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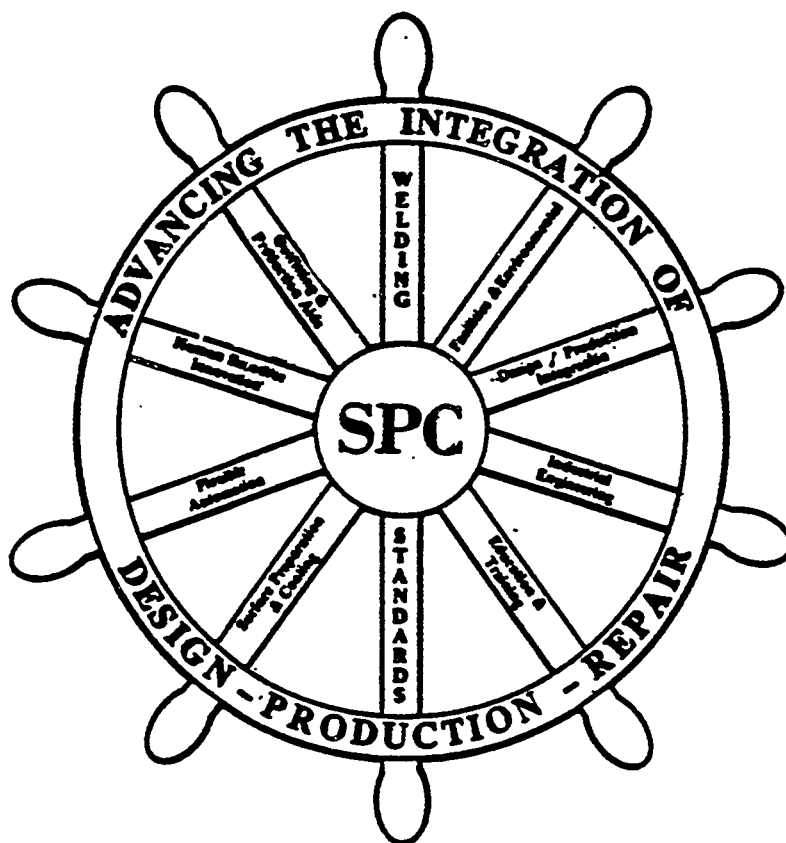
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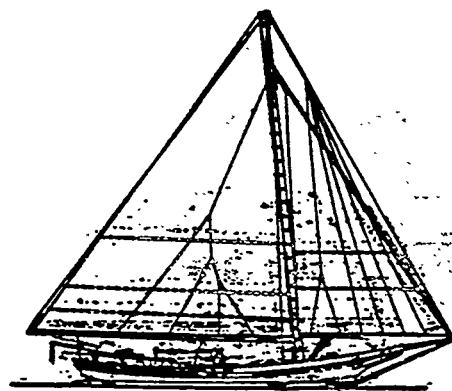
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The First Time Integration of Product by Stage of Construction with Cost/Schedule Control Application

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ABSTRACT

There is nothing upon which shipbuilding managers and planning theorists are more solidly agreed than the need to optimize the integration of a steel hull with the maximum outfitting that can be achieved, at a point in time that considers the facility, material, and available manpower, in other words, OPPORTUNITY.

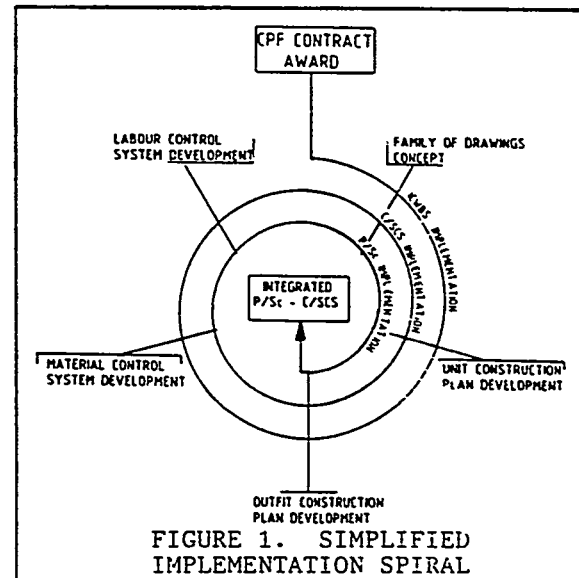
Now, couple this OPPORTUNITY with a doorway through which a manager can enter the whole domain of COST/SCHEDULE CONTROL (C/SC) objectives. Through these objectives the manager has access to a system capable of dealing with the multiple dimensions of organizational and product performance.

This paper addresses the successful integration of PRODUCT BY STAGE OF CONSTRUCTION (P/Sc) with the fundamental principles of C/SC and the specific requirement to provide meaningful performance data in managing a major military defense program on schedule and within cost.

1. BACKGROUND

1.1 THE CANADIAN PATROL FRIGATE PROGRAM

In July 1983, the Canadian Government awarded Saint John Shipbuilding Limited (SJSL) a \$3.26 billion contract to design and construct six city class frigates. The scope of the Canadian Patrol Frigate (CPF) project includes the design, construction, trials, delivery and life cycle support of six fully supported, operational warships and provides for training facilities and programs, logistical support and spare parts.



The CPF project represents a landmark in Canadian military procurement history. For the first time, the Government's procurement strategy has delegated total systems responsibility and risk management to a civilian contractor.

To meet the CPF challenge, SJSL as the prime contractor has developed in Saint John, New Brunswick a Center of Excellence for warship design and construction second to none in North America. Expertise has been established in the areas of Program Management, Design and Engineering, Ship Construction, Integrated Logistics Support, Quality Assurance and Industrial Benefits.

In recognition of this Center of Excellence, the Government of Canada awarded an amended contract for six additional frigates to SJSL in December 1987. The combined contract value of this twelve ship program is \$6.2 billion. It should be noted that, while construction responsibility in the original six ship contract was split evenly

between Quebec and New Brunswick for reasons of regional distribution, the second six frigates will all be built in Saint John, further acknowledging SJSL's excellence Ship Construction and Program Management.

SJSL's stated objectives to meet the challenges of the future are:

- o continued implementation of new technologies to increase productivity and performance
- o development of facilities to accommodate modern naval ship construction and support
- o development of facilities to provide life cycle support and maintenance for the Canadian Patrol Frigates.

1.2 COST/SCHEDULE CONTROL ON THE CANADIAN PATROL FRIGATE PROGRAM

Cost/Schedule Control (C/SC) is a relatively new concept to Canadian industry, although it has been used for performance measurement on major acquisition contracts in the United States for over twenty years. While the initial design for the Canadian Patrol Frigate was still being put to paper, specifications were being written to adapt the United States Cost/Schedule Control System Criteria to the requirements of the CPF program. This adaptation would slightly change the distribution of the elements of the Criteria, but the effectiveness and efficiency would not be impacted (see Figure 2). The acceptance of C/SC Criteria was motivated by the Canadian Contracting

U.S. C/SC CRITERIA <u>SUB-SYSTEMS</u>	CANADIAN c/se CRITERIA <u>SUB-SYSTEMS</u>
-ORGANIZATION	-ORGANIZATION
-PLANNING AND BUDGETING	-WORK PLANNING AND AUTHORIZATION
-ACCOUNTING	-SCHEDULING
-ANALYSIS	-BUDGETING AND -CONTRACT BUDGETING
-REVISIONS AND ACCESS TO DATA	-ACCOUNTING
	-DATA ACCUMULATION
	-ANALYSIS
	-REVISIONS

FIGURE 2. DIFFERENCES BETWEEN CANADIAN AND U.S. C/S CRITERIA

Authority's concern about the proper management of cost and schedule performance on this multi-billion dollar contract.

The primary objective of the Canadian C/SC Criteria was to ensure that the resultant systems would provide the basic principles of cost and schedule management and ensure that:

- o all CPF work was defined and assigned
- o an integrated baseline plan for the performance of the contracted work be established, including:
 - definition of work scope and assignment of responsibility
 - scheduling of the outputs of each segment of work scope, as well as sufficient overall scheduling to provide proper integration of all program work scope
 - the timephasing of all program budgets
 - the establishment of controls to monitor and measure the performance of the work
 - recording of all program costs against the baseline structure
 - identification and monitoring of deviations from the plan
 - control of changes to the baseline plan
 - maintenance of valid estimates of cost to complete the work of the CPF program.

The refined Canadian Cost/Schedule Control Criteria reads like a primer of basic management principles. So basic was the Criteria that it remained unchanged through all the contract negotiations preceding contract award. A further endorsement of the Criteria is SJSL's adoption of this approach to cost and schedule control for its own internal management systems.

2. IMPLEMENTING A COST/SCHEDULE CONTROL SYSTEM

Through the Canadian Government's approach to implementing the Cost/Schedule Control Criteria, SJSL and its three major subcontractors were encouraged to develop an effective planning and control system suited to their own needs.

The Criteria was designed to allow prime and subcontractors to use the management procedures of their choice, while providing an outline of characteristics and capabilities which the Canadian Patrol Frigate Program Management Office (CPF PMO) deemed necessary for an effective

cost and Schedule Control system.

This system would provide valid, timely and auditable information indicative of progress, would properly relate cost, schedule and technical performance and satisfy the Canadian Government's requirement for summarized program information and visibility into potential problems.

The Criteria was intended to provide SJSL with maximum flexibility in managing internal operations. From the start, it was a CPF PMO policy to avoid imposing unnecessary changes on existing SJSL systems and to minimize other changes whenever possible. Originally, CPF PMO envisioned a single internal system which would satisfy both SJSL's management requirements and CPF PMO's need for information. The system must also provide for the clear definition of total CPF contractual effort with an Integrated Contract Work Breakdown Structure (ICWBS). The ICWBS is simply a sub-division in family tree format of products, components, work tasks and services required to achieve a desired goal or produce an end-product (see Figures 3 and 4).

2.1 THE CANADIAN C/SC CRITERIA

A major strength of the Canadian C/SC Criteria is that it does not prescribe specific methods of organization operation, but rather, provide: vigorous standards against which to measure the adequacy of management control systems. The CPF contract granted SJSL the freedom to organize its C/SC system in a manner consistent with its own management philosophy. However, the composition of that system must successfully embrace the following sub-systems:

I. ORGANIZATION: The Criteria elements applicable to Organization require that SJSL arrange all contract-authorized work in the framework of the Work Breakdown Structure (WBS) down to a manageable level (see Figure 5). Designated key management personnel at SJSL are assigned responsibility for portions of the manageable levels of the WBS, resulting in a number of control points. All SJSL activities (planning, scheduling, budgeting, work authorization, cost accumulation) operate on this basis. Elements for identifying work scheduled, work performed, actual costs incurred, budget and estimate

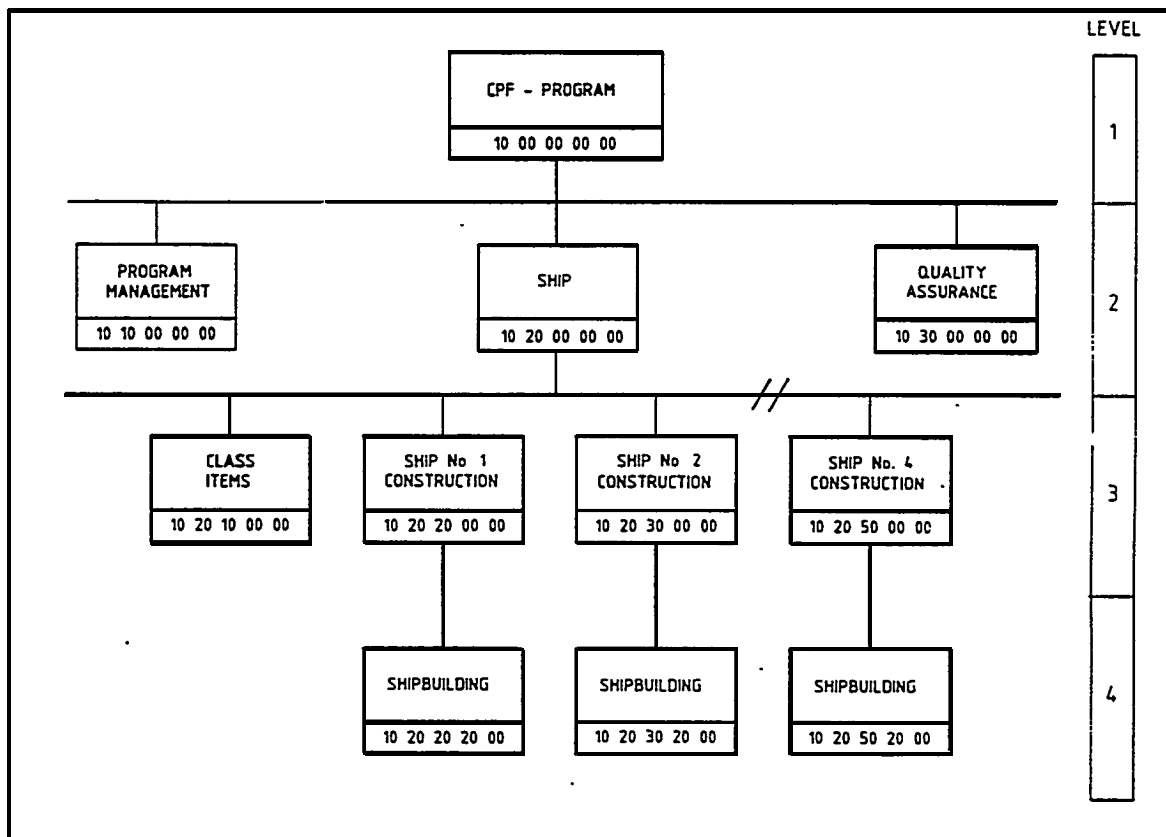


FIGURE 3. THE CPF INTEGRATED CONTRACT WORK BREAKDOWN STRUCTURE (LEVEL 1-4)

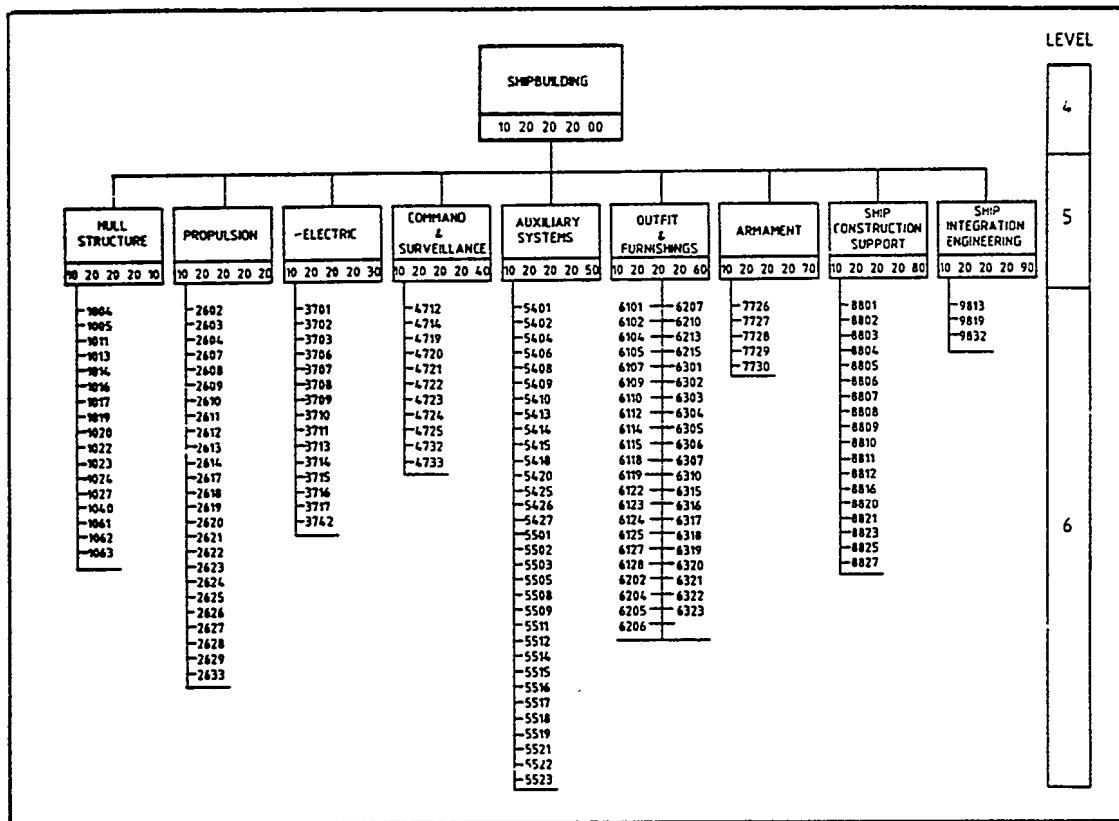


FIGURE 4. THE CPF INTEGRATED CONTRACT WORK BREAKDOWN STRUCTURE (LEVEL 4-6)

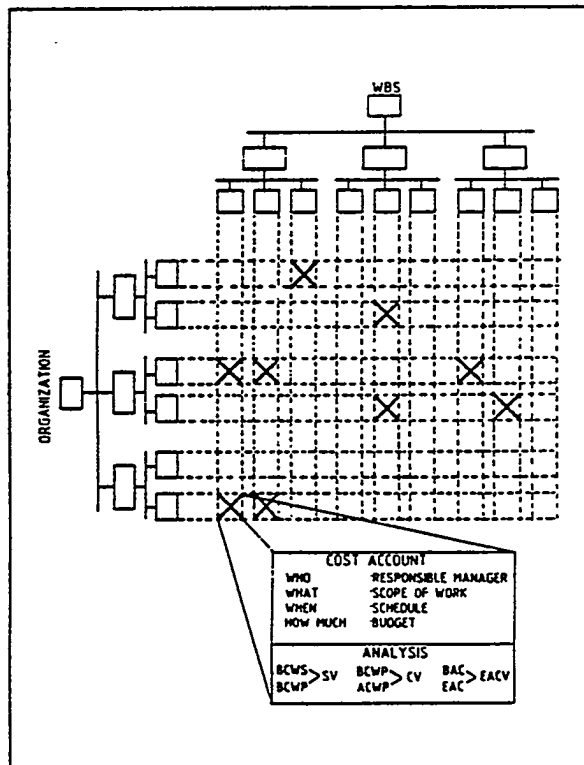


FIGURE 5. CPF WORK BREAKDOWN STRUCTURE EXTENSION

at completion, and cost and schedule variances must be utilized at the selected control points. The criteria apply to all work, whether direct, overhead or subcontractor oriented.

11. WORK PLANNING AND AUTHORIZATION: Criteria elements relating to Work Planning and Authorization require that SJSL plan all contract-authorized work to the extent practicable and ensure that near term work is planned in detail. Work must be planned in the manner in which it is to be performed, and be amenable to in-process objective measurement. Finally, all work must be adequately budgeted on the basis work content.

III. SCHEDULING: Criteria elements applicable to Scheduling require SJSL to develop a top down scheduling system with a top level schedule containing key contract requirements, supported by lower level schedules identifying areas interface/interdependency of key completion dates (Figure 6). The scheduling system must descend to the lowest level where work is performed. At this level, and from this level through to the top level schedule, SJSL must be able to report progress against stated requirements/key events, and use this progress

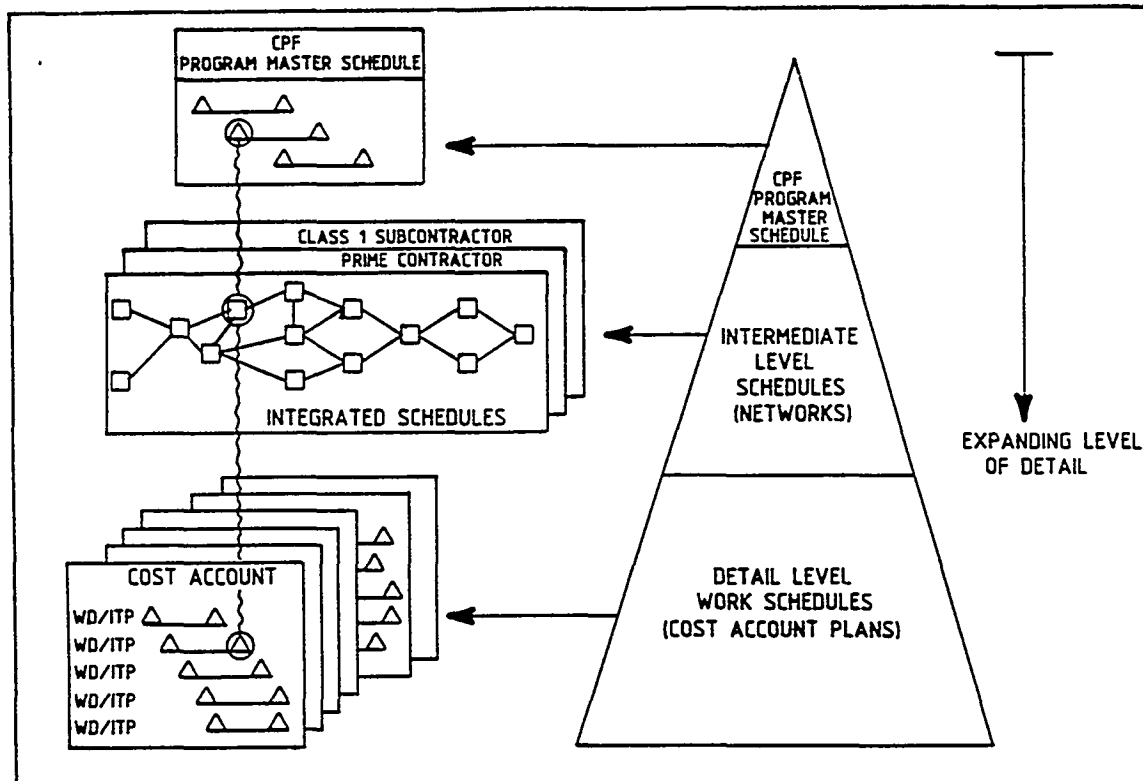


FIGURE 6. CPF INTEGRATED MASTER SCHEDULE

information to forecast completion dates for all events. The Integrated Master Schedule (IMS) was developed to meet these needs.

IV. BUDGETING AND CONTRACT BUDGETING: Criteria elements applicable to Budgeting and Contract Budgeting require SJSL to establish and maintain a timephased budget baseline for performance measurement purposes. Overhead budget determination is to be a rational, traceable process based on SJSL's anticipated business base. All overhead projections beyond the current year must be applied systematically and adjusted in a timely manner.

v. ACCOUNTING: Criteria elements applicable to Accounting require SJSL to manage the utilization of Management Reserve and Undistributed Budget, reconcile the Contract Target Cost and all budgets for internal work, record direct cost on an applied or other acceptable basis consistent with the budgets in a formal system controlled by the General Books of Account, and ensure the Material system further effects performance measurement. Direct costs from the lowest level of cost collection must be summarized to the total contract level through the WBS and the functional organization in a consistent manner. Indirect costs

must be summarized as well, and work accomplishment against the schedule must be identified. Finally, SJSL must ensure that only that work which cannot be planned in discrete, short span or measured effort work packages is classified as Level of Effort (LOE) work.

VI. DATA ACCUMULATION: SJSL is required to provide CPF PMO access to all pertinent records and documentation.

VII. ANALYSIS: Criteria elements applicable to Analysis require that SJSL generate cost, schedule and at-completion variance data and be able to explain the problem cause, impact and proposed corrective action associated with significant variances. This performance measurement is to be applied to both subcontracted and internal work (direct and overhead). Internally, this performance measurement must address the total contract level to the level where work is performed, through both the functional organization and the WBS. SJSL management use this data and corresponding variance narrative to detect and avert potential problems.

VIII. REVISIONS: SJSL is required by the Criteria to incorporate approved internal and contractual changes in a timely manner and ensure that the net

effects of these changes are provided for in existing budget, schedule and work scope. All such changes must be documented and logs maintained to demonstrate traceability to original assignments of budget, schedule and work scope. Retroactive changes, with the exception of errors and routine accounting adjustments, are prohibited.

2.2 THE OUTPUT OF A FUNCTIONAL C/SC SYSTEM: DATA CATEGORIES

C/SC allows Canadian Government personnel to review cost and schedule performance data, and thereby determine the status of the CPF project, without detailed knowledge of the SJSL management system. The Government relies on accurate, consistent information from SJSL and understands the C/SC reasoning upon which the information is based.

The information generated from the SJSL C/SC system is grounded in sound management practices:

- o all work is defined/assigned
- o all work is scheduled
- o all work is budgeted
- o actual costs are properly collected
- o status evaluations are made
- o final cost predictions are derived.

The Cost/Schedule Control system accommodates formalized, established methods for communicating contractor performance.

Upon successful integration of the eight sub-systems (discussed in Section 2.1) which support the C/SC system, information as to the status of the CPF contract work scope becomes available. This information consists of:

Budgeted cost of Work Scheduled (BCWS)

Budgeted cost of Work Performed (BCWP)

Actual Cost of Work Performed (ACWP)

Budget at Completion (BAC)

Estimate at Completion (EAC)

These five data categories depict the precise schedule and cost position, both incrementally and cumulatively, of SJSL and its major subcontractors for a specific scope of work at a specific point in time. They are defined as follows:

BCWS: The budgeted value of work that is planned to be completed in a

specific period. Regarding ship components which are purchased this value represents the budget that has been assigned for vendor work in a specified period.

BCWP: In direct relation to contract work that is scheduled to be completed in a specified period, BCWP represents the value budgeted for work which was completed in a specified period. For work which has been completed, BCWP equals 100% of the total budget assigned. When considering in-process work an objective determination of progress must be made.

ACWP: As a result of the performance of work, expenditures are incurred. cost data accumulated in the accounting system includes employees' completed timecards specifying assigned work activities and invoices for payment to vendors.

BAC : This budgeted value represents the total budget for work to be accomplished. In distinguishing this term from BCKS it is relevant to note that BCKS is a budgeted amount for a specified period (eg. month), while BAC is total budgeted at completion, a summarization of each period BCWS.

EAC : In relation to the BAC, which summarizes the total bud-get for assigned work scope, SJSL as the responsible authority shall periodically assess performance to date and estimate the final cost at completion of all assigned work.

These five data elements are derived at the lowest level within the organization where responsibility is assigned. This information is summarized through a matrix by functional departments and by work breakdown structure element. This breakdown provides immediate focus on areas where there are deviations from the plan.

Figures 7 and 8 illustrate the relationship between the five data elements and the analysis that is performed employing them.

2.3 SUBCONTRACTOR INTEGRATION

In the early stages of the CPF program it was determined that, in the interest of maximizing Industrial

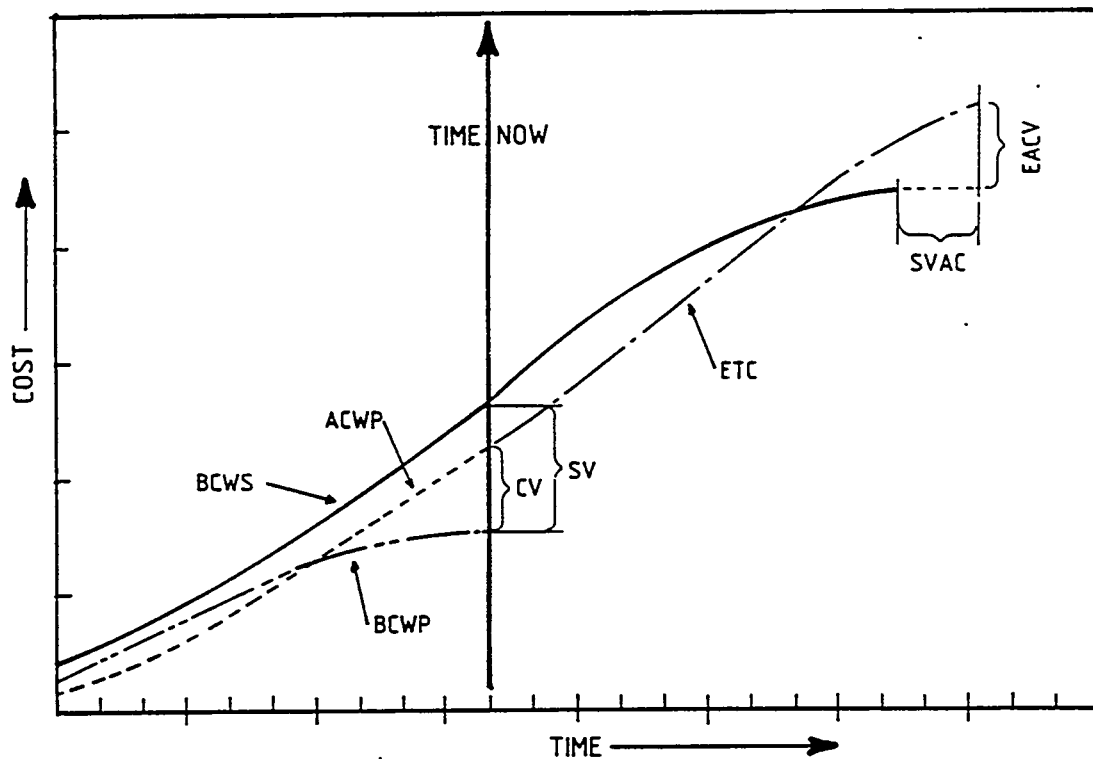


FIGURE 7. CUMULATIVE PERFORMANCE ANALYSIS

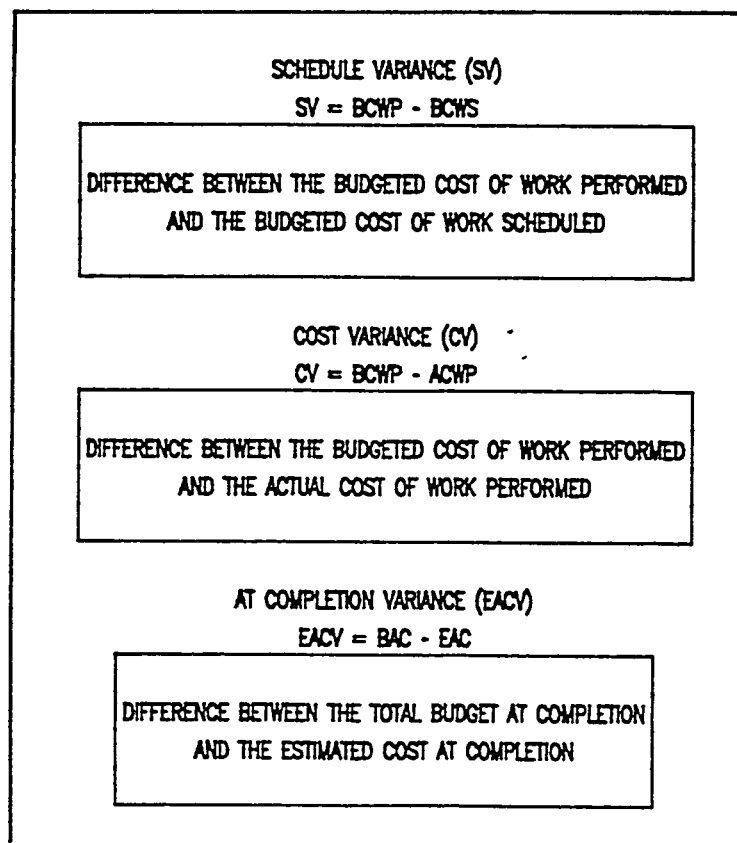


FIGURE 8. THE FIVE DATA ELEMENTS

Benefits throughout Canada and in consideration of the inherent complexities of CPF, certain defined work scope would be subcontracted. As a result of this decision many subcontracts were let. Although all subcontracts may have a potential impact on prime contract cost and schedule parameters, certain large subcontracts were determined to be critical contributors to the successful execution of CPF. These contractors have been assigned an integral role on the CPF contract and therefore require close scrutiny. As a result, SJSL has included in these contracts the requirement for an operational C/SC system combined with monthly cost Performance Report submission.

In relation to the total CPF contract SJSL has maintained responsibility for a significant portion of the contract work scope. The entire combat and communication system was subcontracted, encompassing design, procurement, construction, installation, integration, and testing of all the associated combat systems for six shipsets. Ship system engineering work was also subcontracted; this was integrated with the effort of the SJSL Engineering function in comprising the entire ship design package. Finally, SJSL subcontracted work for the construction of three of the first six city class frigates to a Canadian shipyard in Quebec.

Figure 9 depicts the percentage contribution of each critical subcontractor in terms of contract value. Note that the criticality of the supporting design agent is based more on schedule impact than on cost.

In December of 1987, SJSL's CPF contract was amended to include six additional frigates. This lengthened and increased the value of the prime contract and had an associated effect on the combat/communications subcontract (see Figure 10).

The requirements imposed on critical subcontractors are similar to those placed on SJSL. Each subcontractor is required to demonstrate that its system meets the criteria contained in the contract. SJSL's role is to determine whether the system satisfies contractual obligations and is consistent with and supportive of the SJSL system. CPF PMO as the customer oversees this system demonstration and provides input through SJSL.

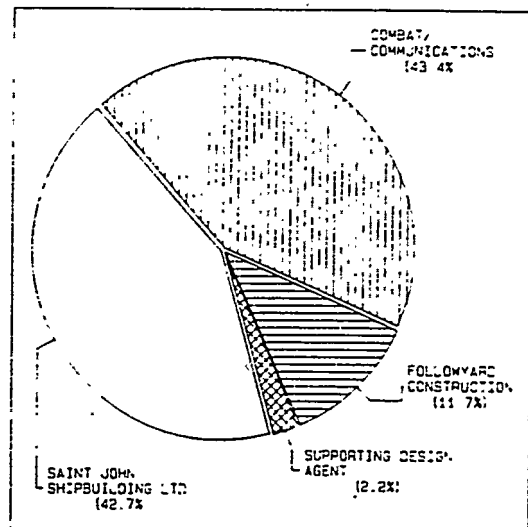


FIGURE 9. THE CPF CONTRACT SPLIT OF WORK (ORIGINAL CONTRACT)

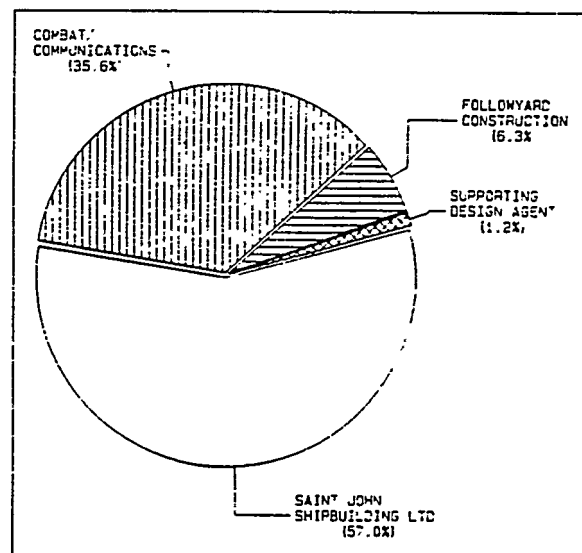


FIGURE 10. THE CPF CONTRACT SPLIT OF WORK (AMENDED CONTRACT)

2.4 THE OUTPUT OF THE COST/SCHEDULE CONTROL SYSTEM: THE COST PERFORMANCE REPORT

Critical subcontractors are required by contract to submit monthly Cost Performance Reports (CPRs) which contain pertinent cost and schedule data. These subcontractor cost Performance Reports provide SJSL with the requisite visibility to manage the CPF contract. Upon receipt, subcontractor reports are distributed to the appropriate management for

action and inclusion in the analysis which is forwarded to CPF PMO as part of the prime contract deliverable, SJSL's CPR.

The CPR consists of five standard formats (Figure 11) which summarize cost and schedule status and provide a complete overview of the CPF contract so that issues, program impacts and performance trends are identifiable. The CPR contains:

- o Contract data (headings)
- o ICWBS and Product by Stage of Construction performance (informal reports), budgets and EAC (Format 1)
- o Prime and subcontractor organizational performance, budgets and EAC (Format 2)
- o Baseline budget distribution and record of changes (Format 3)
- o Timephased manpower plan and/or forecast (Format 4)
- o Discussion of problems (Format 5).

This information from the major subcontractors is integrated with SJSL's data to form the Total Program Cost Performance Report (see Figure 12).

FORMATS 1 AND 2

The same principles apply to review the data contained in Formats 1 and 2 as they display the same overall performance data in the same format. However, Format 1 shows a line item breakdown of ICWBS elements at the reporting level, while Format 2 shows a breakdown of the performance of the major functional organizations and three major subcontractors.

Additionally, Formats 1 and 2 provide the data necessary to perform trend analysis. Cumulative performance (BCWS, BCWP and ACWP) may be plotted monthly to provide the classic S-curve of the three performance elements.

FORMAT 3

This format shows the timephased contract budget baseline, performance measurement baseline (PMB). It also quantifies all approved changes to the PMB, provides visibility into the effect of changes, and recognizes any application of Management Reserve.

FORMAT 4

This format reports the timephased estimate of labor required to complete the CPF contract and contains the data best suited for trend extrapolation and regression analysis.

FORMAT 5

Format 5 provides an analysis of performance with both graphic and narrative explanations of cost, schedule and at-completion variances which meet or exceed the CPF contract variance thresholds (Figure 13). This Format is divided into three sections:

SECTION 1 Contains an executive summary which discusses major problem areas.

SECTION 2 Contains narrative which explains ICWBS reporting level variances.

SECTION 3 Covers any additional variances exceeding CPF contract thresholds as well as changes not covered in Sections 1 and 2.

2.5 C/SC VALIDATION

The CPF contract contains the Criteria requirements for a C/SC system. SJSL developed a C/SC system using these Criteria as a guideline. The necessary computer software program was written and the management systems were established. On numerous occasions during the implementation phase, SJSL invited CPF PMO to review the development of the system; CPF PMO provided valuable input regarding their interpretation of the Criteria requirements. To ensure that SJSL's system would meet the newly designed C/SC Criteria, SJSL was contractually obligated to demonstrate its system's sufficiency to a CPF PMO review team. Once this team approved (validated) SJSL's C/SC system, further demonstrations would not be necessary, provided CPF PMO surveillance indicated SJSL's continued compliance with the Canadian C/SC Criteria.

In December of 1987 CPF PMO provided formal notification that SJSL's C/SC system was validated, representing the FIRST validation granted by the Canadian Government to a Canadian Company on a Canadian Military Contract. SJSL is fully committed to maintaining the C/SC system as validated, however modifications will be made to meet future requirements of both SJSL and the customer. CPF PMO shall monitor the system in a surveillance mode to ensure continuing compliance with the C/SC Criteria.

Reviews of CPF critical subcontractors have been conducted by

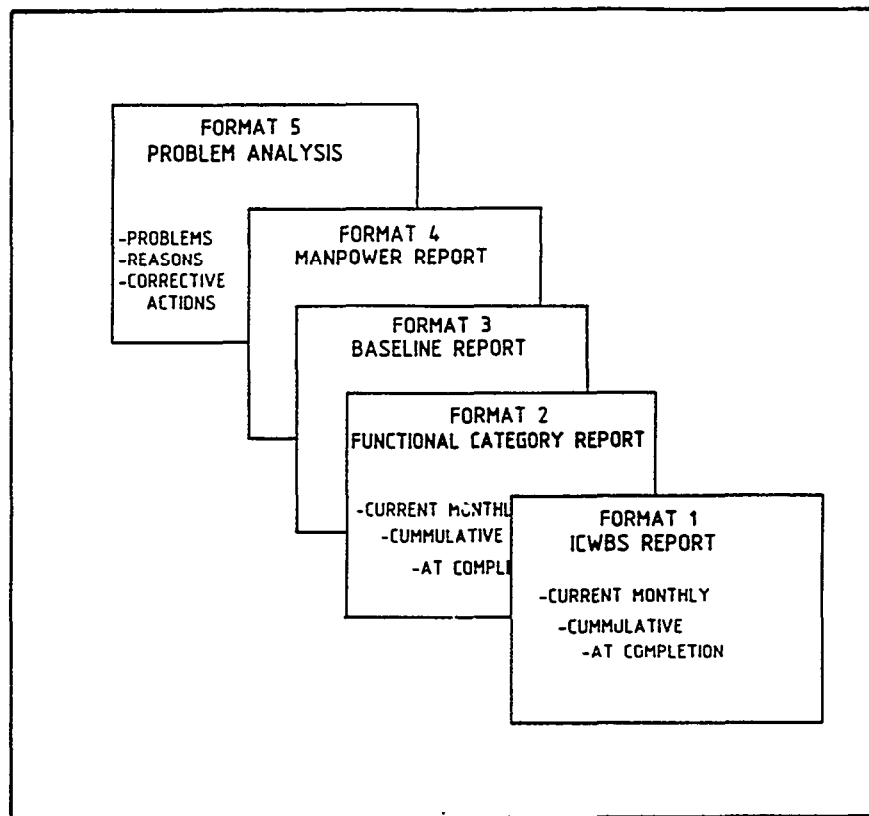


FIGURE 11. THE FIVE FORMATS OF THE CPR

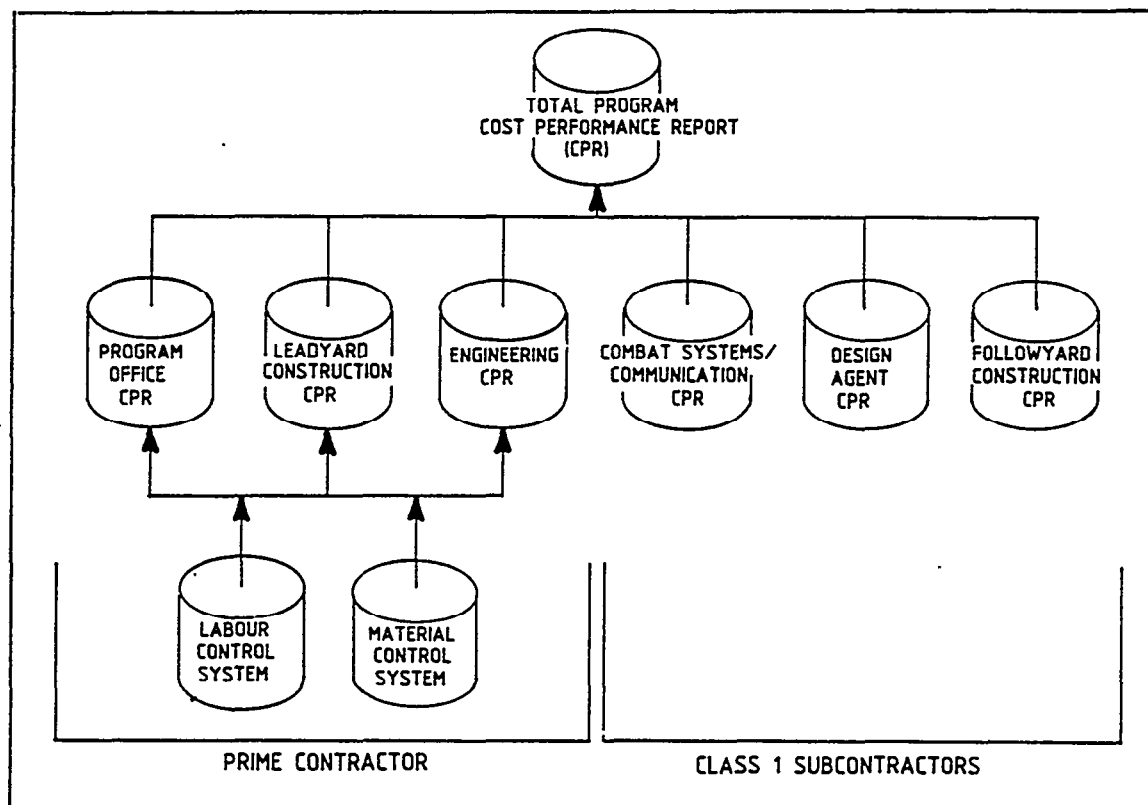


FIGURE 12. THE INTEGRATION PROCESS TO LINK THE CLASS 1 SUBCONTRACTORS INTO THE PRIME CONTRACT CPR

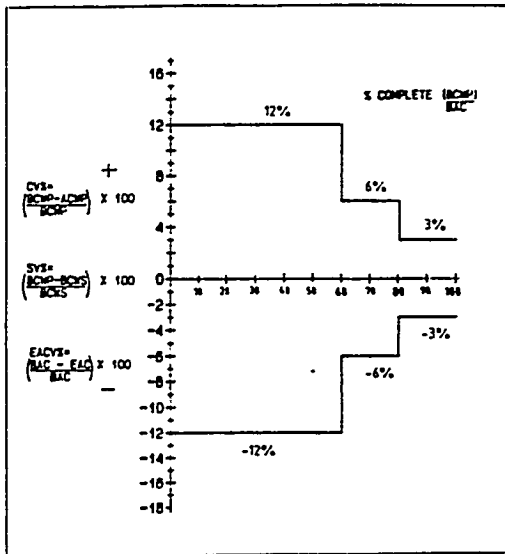


FIGURE 13. CPF CONTRACT VARIANCE THRESHOLDS ENVELOPE

SJSL and observed by CPF PMO, however none of these organizations has received C/SC system validation at time of writing. SJSL is expending considerable effort assisting its subcontractors to achieve acceptable C/SC system implementation based on experience gained during SJSL's validation process.

3. IMPLEMENTING PRODUCT BY STAGE OF CONSTRUCTION (P/Sc)

3.1 INTRODUCTION

SJSL defines Product By Stage of Construction (P/Sc) in one word - OPPORTUNITY.

In understanding OPPORTUNITY it is important to realize that a shipyard decision to commit resources to some specific early use on a stage of construction, or to utilize more rather than less resources to accomplish a task at the optimum time, is also an implicit decision not to commit these resources to traditional ICWBS approaches. What these resources accomplish when committed at the optimum stage of construction is OPPORTUNITY.

3.2 DEFINITION OF P/Se

P/Se is the sub-division of the ship into readily identifiable pieces of work. Each piece of work is called an interim identifiable objective of production (eg. a fabricated part or sub-assembly, an assembly unit or module).

The sub-division of the ship is accomplished using the zone-by-stage approach, that is by considering each area of the ship and determining the optimum stage at which to do the work. OPPORTUNITY.

P/Se breaks the ship down into groups of similar parts, interim products, which are then designed and manufactured in batches at the most logical stage. OPPORTUNITY.

3.3 STAGES OF CONSTRUCTION (PRODUCTION OPPORTUNITY LEVELS)

Planning ship construction in eight production OPPORTUNITY levels is a practical way to promote the optimization of work flow.

P/Se views ship construction as a series of OPPORTUNITY levels, called stages or work centres, through which interim products pass to culminate in the complete ship.

Figures 14 and 15 illustrate the ship's eight production OPPORTUNITY levels, from delivery of raw materials and components to final acceptance by the customer.

NOTE : An OPPORTUNITY level is the optimum level at which the work can be accomplished.

This sub-division is the key to P/Sc. The overlay of defined levels of outfit and painting, coded according to the production OPPORTUNITY level in question, allows planning and control of progress on the ship.

3.3.1 LEVEL 1: KITTING/PART FABRICATION

Part Fabrication is the first production OPPORTUNITY level. Part Fabrication produces components for the ship which cannot be further sub-divided. Typical work orders are issued by unit, stage, and standard manufacture (batch).

Within the classifications, problem areas may be sub-divided by machine requirements, type of material, size, etc.

STAGE	TYPE OF WORK
1110	Shotblasted Plates & Shapes
1120	Marking, Cutting Plates & Shapes
1130	Forming Plates & Shapes
1150	Drain Plugs, Thermometer Plugs

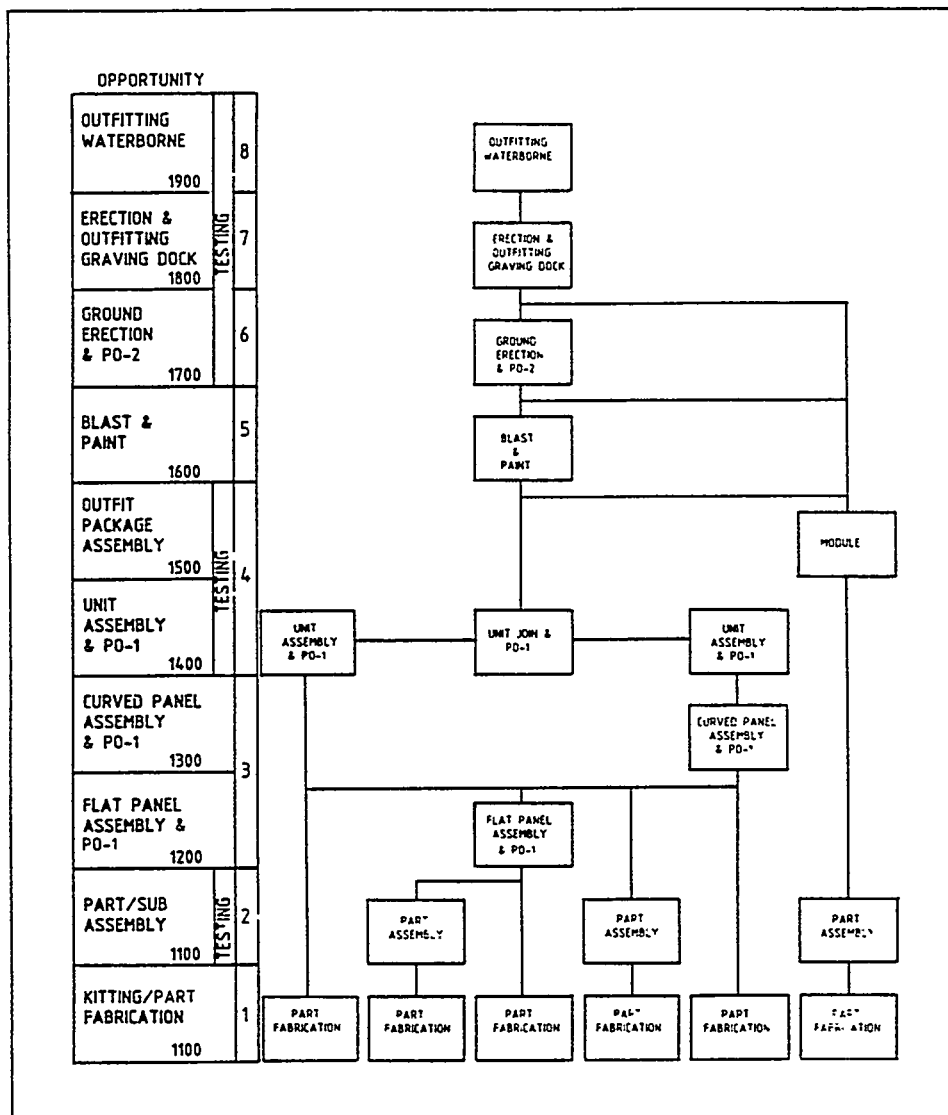


FIGURE 14. TYPICAL PRODUCTION OPPORTUNITY LEVELS FLOW CHART

STAGE	TYPE OF WORK
1160	Material Kitting, Bending or Cutting
1170	Marking, Cutting Plates & Shapes
1180	Marking, Cutting Wood Panels
1190	Marking, Cutting Electrical Cables

3.3.2 LEVEL 2: PART/SUB-ASSEMBLY

Part/Sub-assembly is the second production OPPORTUNITY level. Typical work orders are issued by unit and area.

STAGE	TYPE OF WORK
1140	Fitting Beams, Girders, Web Frames
1150	Fitting Liner on Shaft
1160	Fitting, Welding Pipe Pieces
1170	Fitting, Welding Foundations & Tanks

STAGE	TYPE OF WORK
1180	Fitting Cabinet Pieces Together
1190	Fitting Connectors To Cables

3.3.3 LEVEL 3: FLAT AND CURVED PANEL ASSEMBLY AND PRE-OUTFITTING

The third production OPPORTUNITY level is a sub-unit and initial pre-outfitting level consisting of a number of fabricated and/or assembled parts. Typical work orders are issued by unit and area.

STAGE	TYPE OF WORK
1200	Flat Panel with Penetrations Foundations & Backing Structure
1300	Curved Panel with Overboard Discharges, Foundations & Backing Structure

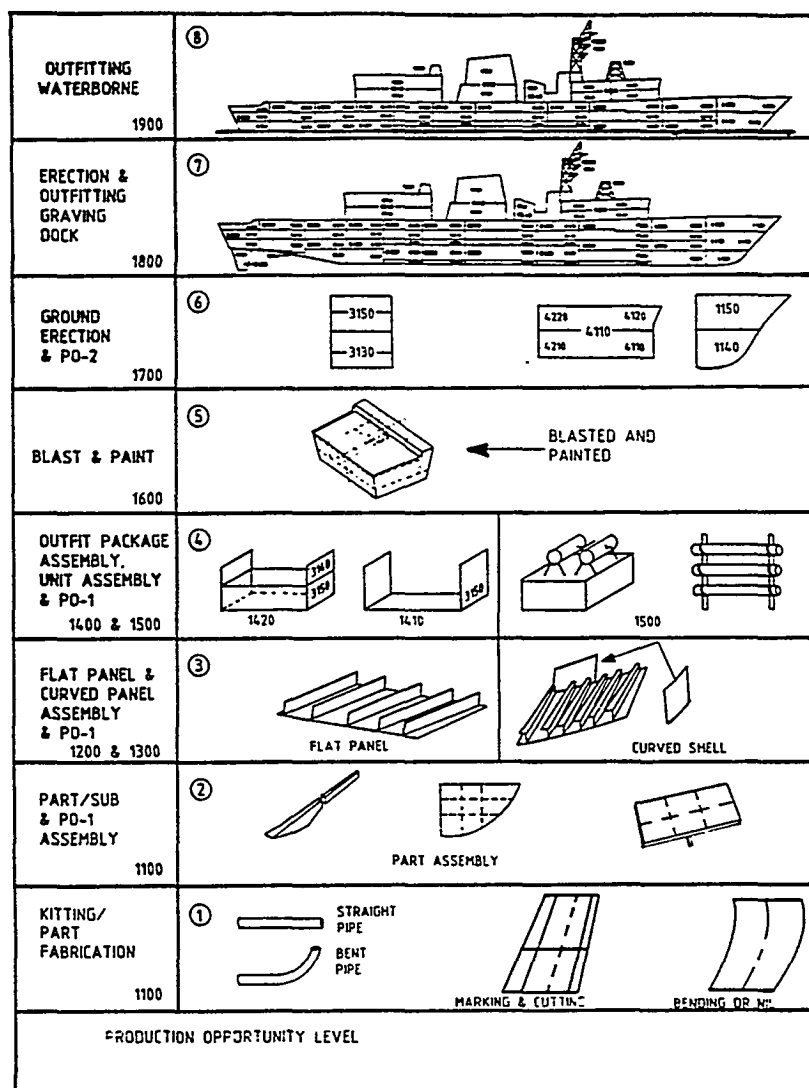


FIGURE 15. WORK ORGANIZATION BY STAGE OF CONSTRUCTION

3.3.4 LEVEL 4: MODULE - ASSEMBLY /PRE-OUTFIT AND JOIN

The fourth production OPPORTUNITY Level involves final module production, including integration of flat panel units with pre-outfit, curved panel units with pre-outfit to form a block which can be further outfitted and tested.

STAGE	TYPE OF WORK
1410	Pre-outfit 1 (PO-1) Inverted
1410	Pre-outfit 1 Upright
1420	Assembly Unit Join
1420	Final Pre-outfit 1
1500	Modules

3.3.5 LEVEL 5: BLAST & PAINT

The fifth production OPPORTUNITY level is Blast & Paint, the stage at

which surface preparation and painting take place. Considerable planning is performed at this stage to minimize the on-board painting.

3.3.6 LEVEL 6: GROUND ERECTION AND PRE-OUTFIT 2

The sixth production OPPORTUNITY level is clearly defined by its output of erection units which will require additional pre-outfit (the remainder of PO-1 as well as PO-2, which is cold work pre-outfit).

3.3.7 LEVEL 7: ERECTION & OUTFITTING IN GRAVING DOCK

The seventh production OPPORTUNITY level is Erection & Outfitting in the Graving Dock, and entails the fitting and welding together of erection

units to form the ship. It includes a defined level of outfit covering major component installation (e.g. gas turbines, cruise diesel, main cable runs) and the remainder of outfitting in way of erection unit butts.

3.3.8 LEVEL 8: OUTFITTING WATERBORNE

The eighth and final production OPPORTUNITY level, Outfitting Waterborne, is the most expensive. Level 8 includes the installation of all miscellaneous outfit components, final compartment completion and final system testing and acceptance of the ship.

3.3.9 STAGES OF CONSTRUCTION (PRODUCTION OPPORTUNITY LEVELS & NUMBERING)

A four digit number is used for identifying material and labor to a work center at the shipyard as listed below:

STAGE	TYPE OF WORK
1100	Kitting, Part Fabrication & Assembly
1200	Flat Panel Assembly & PO-1
1300	Shell Assembly & PO-1
1400	Unit Assembly Join & PO-1
1500	Outfit Assembly
1600	Package Blast & Paint
1700	Ground Erection & PO-2
1800	Erection & Outfitting in Graving Dock
1900	Outfitting Waterborne

3.4 THE PRODUCT

The ship is divided into five different types of products: Units; Outfit Zones; Special Installations; Modules; and Standard Manufacturing Jobs.

The following discussion describes the products in detail and illustrates the manner in which they are coded according to their position within the ship.

3.4.1 UNITS

Units are geographically oriented divisions of the ship by Superzone, Girth, and Level. The configuration of the unit is determined by the structure and design of the ship, the facilities which are available, and the construction and outfitting plan.

Units and pre-outfit zones comprise the pre-erection product. An assembly unit is a defined single deck level

structure, usually shell to shell but occasionally broken into port, starboard and centerline sections. Erection units are typically composed of more than one assembly unit. (See Figure 16.)

3.4.1.1 UNIT NUMBERING

A four digit number in the format XYZO is used to label and schedule material and labor resources for a unit/pre-outfit zone. Unit zone numbers have a geographical significance within the ship and allow personnel to rely on logic rather than memory to control material and labor.

x Represents one of four major Superzones of the ship:

1. Forward of Machinery spaces
2. Machinery spaces
3. Aft of Machinery spaces
4. Superstructure

Y Within a Superzone the ship is sub-divided further and is numbered forward to aft (see Figure 17). This represents Girth sub-divisions (1 through 9) based on major vertical sub-divisions.

z Represents the deck level. Numbers run consecutively (1 through to 9) from the inner bottom to the weather deck for hull unit/zones. For superstructure, the numbering runs from bottom to top as well, using major structural horizontal sub-divisions.

o Reserved for further sub-division of the basic assembly unit for more efficient design and production cost control as required.

3.4.2 OUTFIT ZONES

Outfit zones are geographically oriented divisions of the ship by Superzone, Girth and Level. The configuration of the outfit zone is determined by the structure of the ship and the plan for outfitting the zone.

Outfit zone boundaries are typically bulkhead to bulkhead and deck to deck. They are the basis for outfit design as well as outfit work, beginning after unit erection. If desired, these boundaries can be to the level of "compartment" for work after erection to monitor cost and schedule for specific areas (eg. electronic spaces).

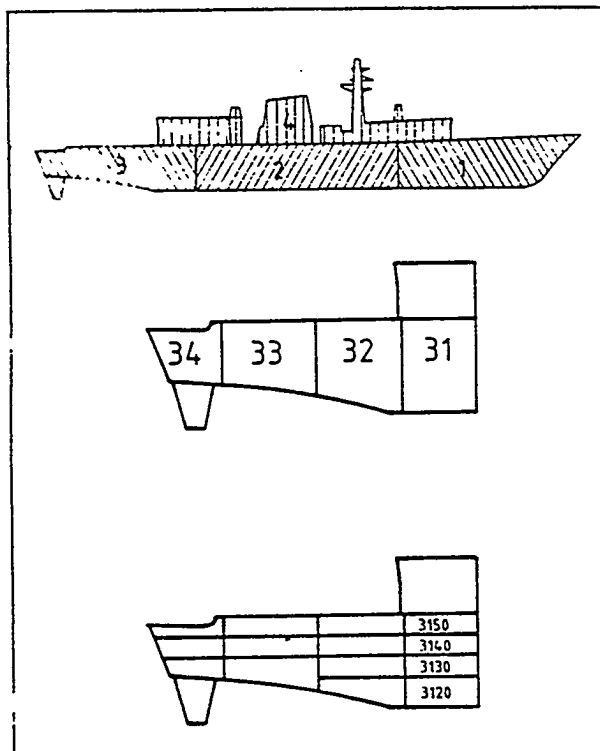


FIGURE 17. AN EXAMPLE OF UNIT NUMBERING

3.4.2.1 OUTFIT ZONE NUMBERING

A four digit number of the XYZO is used for identifying and scheduling material and labor resources to an outfit zone product (Figure 18). Outfit zone numbers have a geographical significance within the ship and allow personnel to rely on logic rather than memory to control material and labor.

X Represents one of four major Superzones of the ship:

1. Forward of Machinery spaces
2. Machinery spaces
3. Aft of Machinery spaces
4. Superstructure

Y Represents Girth sub-divisions (1 through 5) based on watertight bulkhead locations, forward to aft, for the hull zones and major structural vertical sub-divisions for superstructure zones. The number 0 is used to represent applicability to the entire Superzone. The numbers 6 through 9 are used to designate the exterior shell, weather deck and house sides.

Z Represents a deck level within a Girth. Numbers run consecutively (1 through 9) from the innerbottom to the weather deck for hull zones and major structural horizontal sub-divisions for superstructure zones.

O The number zero is reserved for general outfit zone work. Numbers 1 through 9 are reserved for further sub-division of the basic outfit zone for more efficient design and production cost control.

Figure 19 shows the outfit zone for No. 3 Deck. However, in order to expand on the specialized outfitting required within the electrical equipment area, 2442 has been established as a (sub) outfit zone or sub-zone.

Outfit zones may also span more than one deck level: Figure 19 shows No. 2 Deck with outfit zone 2460, the exhaust casing, shaded. This same outfit zone appears on No. 3 Deck as well.

Figure 20 shows the outfit zone breakdown with vertical design/outfit zones. The further sub-division of the basic outfit zone will allow.

- o More efficient use of design resources
- o Smaller and more controllable work packages during outfitting phases
- o More efficient use of production resources
- o More discrete scheduling of the on-board outfitting activities.

3.4.3 SPECIAL INSTALLATIONS

Special Installations are complex installation jobs which require work to be organized around a particular task rather than a geographic area.

Special Installations often require multi-discipline co-ordination and work sequencing between two or more outfit zones.

3.4.3.1 SPECIAL INSTALLATION ZONE NUMBERING

A four digit number in the format XYZO will be used for identifying and controlling production material and labor to Special Installation zones (see Figure 21).

XY Assigned the numbers 61 through 65 to indicate Special Installation, while the second digit (1 through 4) indicates which Superzone the module is in. The number 5 in the Y digit indicates multi-zones. The number 0 in the Y digit represents main cable pulls.

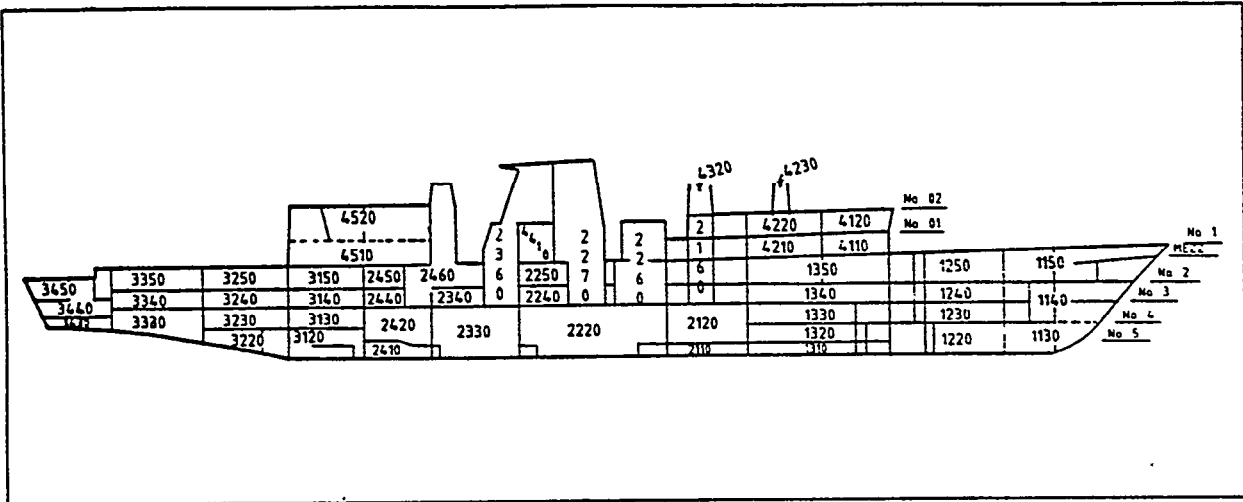


FIGURE 18. THE PRODUCT - OUTFIT ZONE

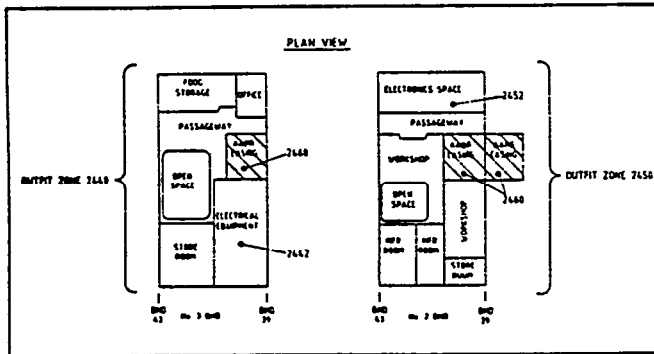


FIGURE 19. AN EXAMPLE OF OUTFIT ZONE

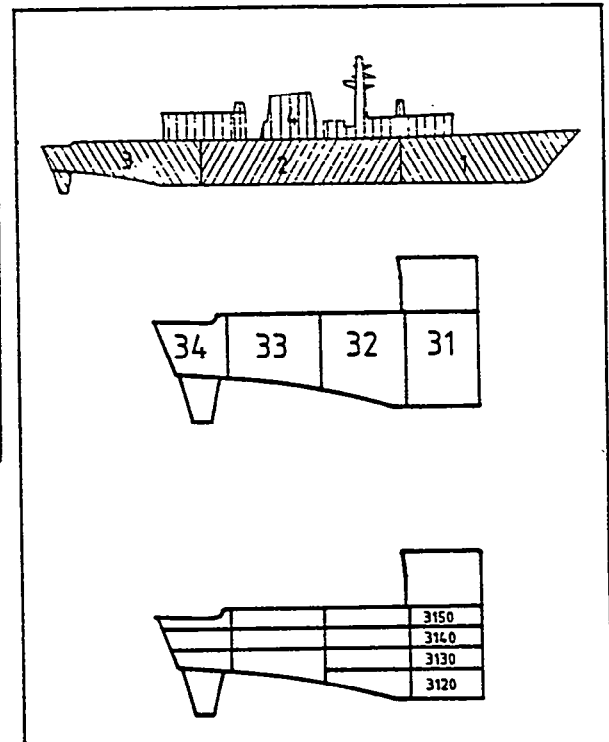


FIGURE 20. AN EXAMPLE OF ZONE NUMBERING

20 A field of consecutive numbers (00 through 99), used to identify the individual Special Installation.

3.4.4 MODULES

A Module is an off-ship and off-unit assembly of outfit equipment, components, material and fittings (often mounted on a common base) which may be installed as a single unit.

Modules are classed by their physical make-up and work content. There are four types of Modules:

- 0 Piping Modules - Major runs of piping and their supports.
- 0 Component Modules - Equipments mounted in shipboard location on their own foundations or mock-ups to allow piping to be run. Depending upon complexity, modules may be broken apart for installation.

STAGE OF CONSTRUCTION									
PRODUCT	KITTING/PART FABRICATION & SUB ASSEMBLY	FLAT PANEL ASSEMBLY & PO-1	CURVED SHELL ASSEMBLY & PO-1	UNIT ASSEMBLY & PO-1	OUTFIT PACKAGE ASSEMBLY	BLAST PAINT	GROUND ERECTION & PO-2	ERECTION & OUTFITTING IN GRAVING DOCK	OUTFITTING WATERBORNE
	1100	1200	1300	1400	1500	1600	1700	1800	1900
	UNITS	WD/ITP	WD/ITP	WD/ITP	WD/ITP		WD/ITP	WD/ITP	WD/ITP
	OUTFIT ZONE	WD/ITP						WD/ITP	WD/ITP
	SPECIAL INSTAL- LATIONS	WD/ITP			WD/ITP		WD/ITP	WD/ITP	WD/ITP
	MODULE	WD/ITP				WD/ITP			
STANDARD MANUFAC- TURING JOBS	WD/ITP								

FIG. 23. THE PRODUCT BY STAGE OF CONSTRUCTION WD/ITP MATRIX

3.5 P/Se NUMBERING

Labour, material and technical information is planned, scheduled and controlled by the P/se Numbering System.

The P/Se Numbering System describes all construction products. It is also flexible enough to accommodate all construction techniques and stages (see Figure 23).

3.6 PICTORIAL EXAMPLES OF P/Se

Photographs included as Figures 24 through 35 depict products, most with pre-outfit completed at optimum stages of construction.

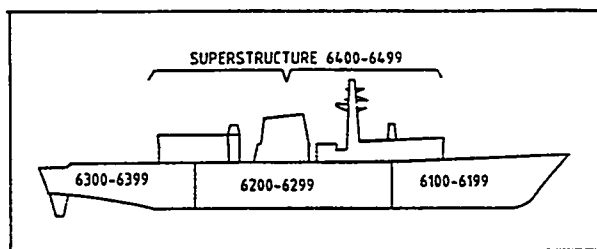


FIGURE 21. AN EXAMPLE OF SPECIAL INSTALLATIONS NUMBERING

- o Tank Modules - Completion of free standing tanks with tank level indication alarm sensors, etc. and testing in the shop.
- o Integrated Modules - The most desirable module where design permits. It includes grating, piping, equipment, ventilation, local cabling, etc. on a common foundation.

Modules can be installed in the following stages of construction:

1. Unit Assembly & Pre-outfit 1
2. Unit Joining & Pre-outfit 2
3. Hull Erection
4. On-Board Outfitting

On-Module Outfitting is targeted at performing as much outfit work as possible off-ship. It ensures that work is performed in the best possible environment and takes maximum advantage of the lowest cost factor available within the shipyard.

3.4.4.1 MODULE NUMBERING

A four digit number in the format XYZO will be used for identifying and scheduling material and labor resources to a module. As with units and zones, the module number has a geographical significance within the ship.

- XY Assigned the numbers 71 through 74 to indicate a module where the second number (1 through 4) indicates which Superzone the module is in.
- ZO Represents a consecutive set of numbers (00 through 99) used to identify individual modules.

As modules have been identified on the CPF program, the Z digit has been used to identify the Girth the module

is located in. For example, the module in forward engine room (Girth 2200) might be 7221 or 7222 or 7223. This convention only exists when less than nine modules are identified (see Figure 22).

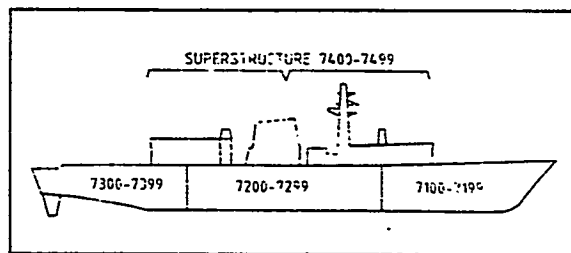


FIGURE 22. AN EXAMPLE OF MODULE NUMBERING

3.4.5 STANDARD MANUFACTURING JOBS

Standard Manufacturing Jobs are special interim products which are built off-flow, that is, outside the main hull construction flow. They are part-assemblies made at Manufacturing Level II.

It is intended that Manufacturing Jobs be grouped according to their common manufacturing characteristics in order to maximize efficiency by making parts in batches.

All Manufacturing Jobs are given **Work Description / Inspection & Test Plan (WD/ITP) numbers** which facilitate planning, scheduling and progressing. Material procurement, fabrication, assembly, painting, testing and QA/QC requirements are all controlled by the P/Se tracking number.

3.4.5.1 STANDARD MANUFACTURING JOB NUMBERING

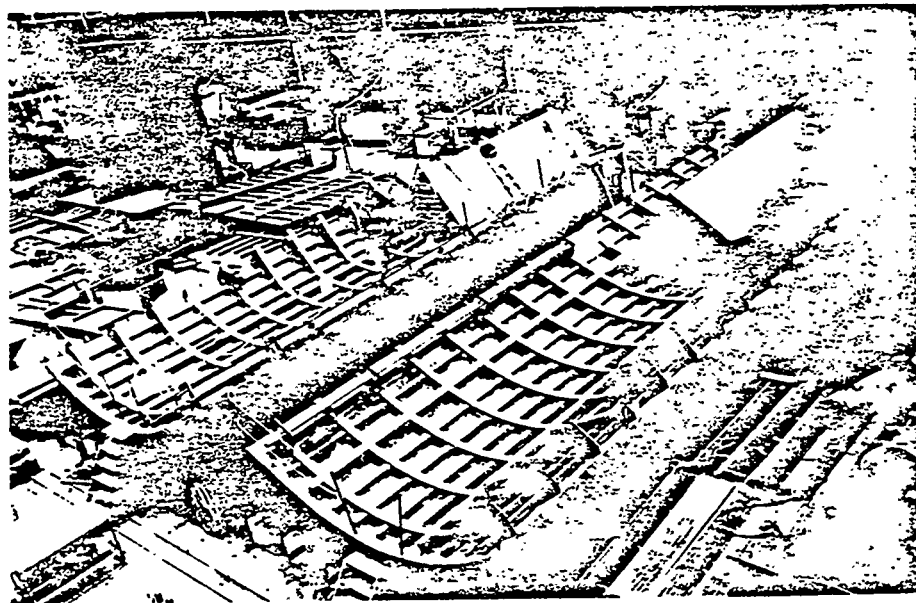
A four digit number in the format XYZO is used. Manufacturing Job numbers have no geographical significance within the ship.

- XY Assigned the numbers 75 through 79 to identify the Manufacturing Job type:

- 75 - Structure
- 76 - Pipe
- 77 - Electrical
- 78 - Sheet Metal
- 79 - Hull Outfit

- ZO A field of consecutive numbers (01 to 99) within the 75, 76, 77, 78, and 79 series to indicate a specific job.

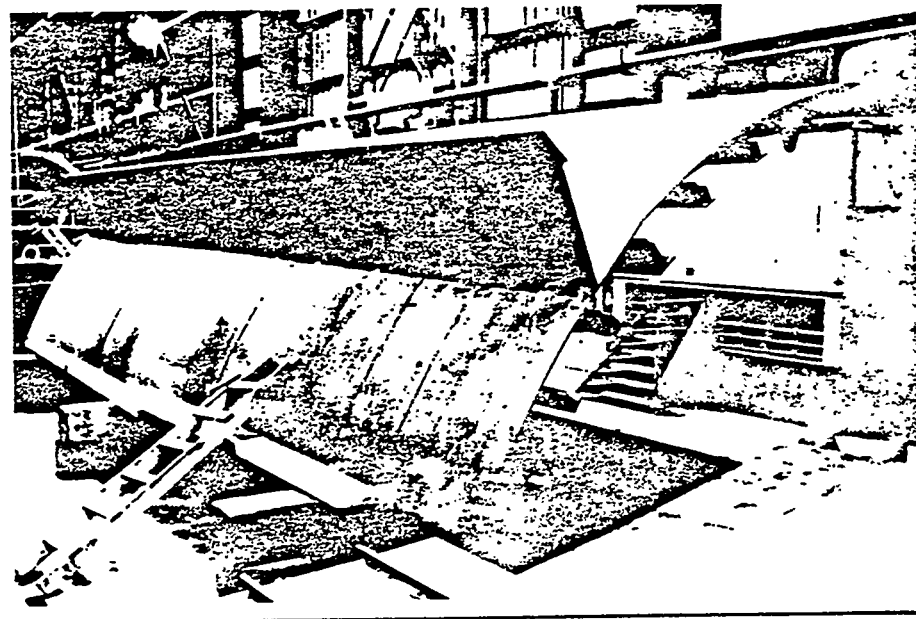
STAGE OF CONSTRUCTION 1300



PRODUCT:UNIT

FIGURE 24. SHELL ASSEMBLY STAGE

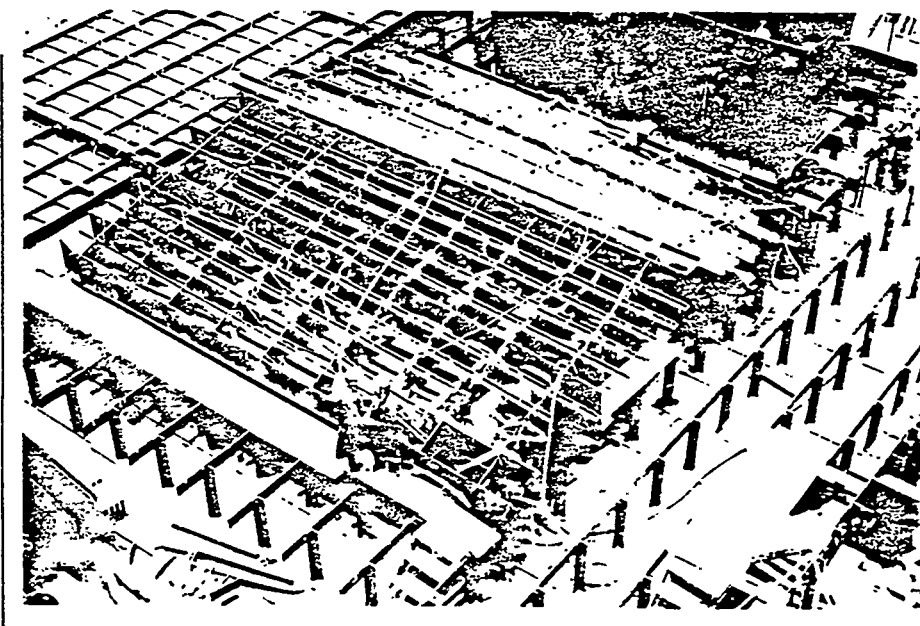
STAGE OF CONSTRUCTION 1300



PRODUCT:UNIT

FIGURE 25. SHELL ASSEMBLY STAGE. BILGE KEEL BEING FITTED INVERTED

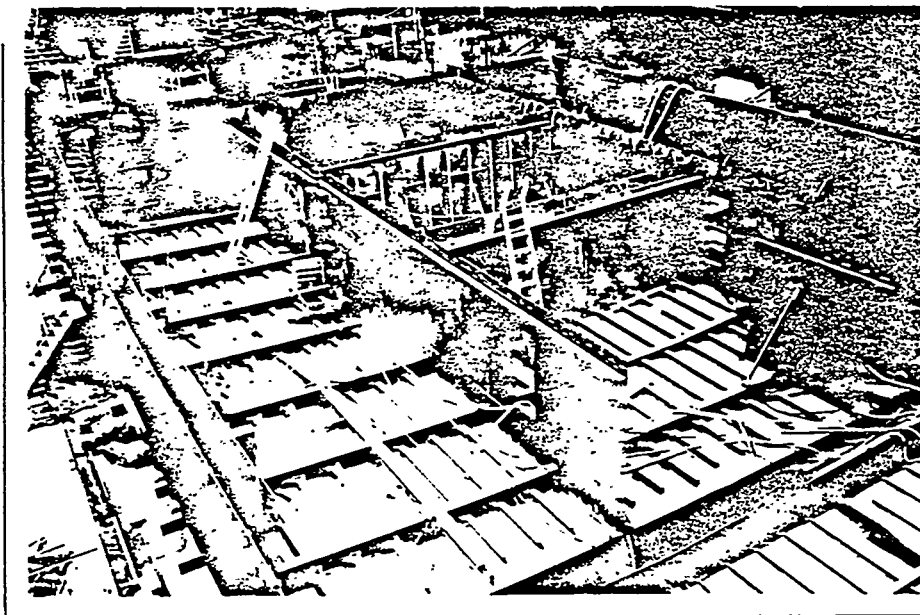
STAGE OF CONSTRUCTION 1410



PRODUCT: UNIT

FIGURE 26. THE UNIT ASSEMBLY STAGE SHOWING PIPES BEING INSTALLED IN THE INVERTED POSITION - OPPORTUNITY UNIT 2410 FUEL TANKS BELOW AFT AUXILIARY MACHINERY ROOM

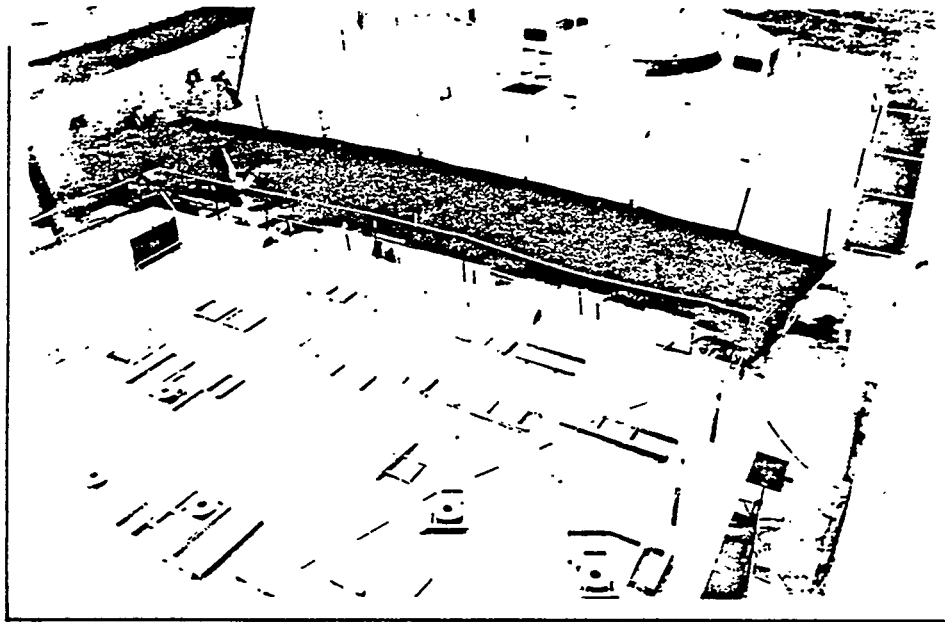
STAGE OF CONSTRUCTION 1410



PRODUCT: UNIT

FIGURE 27. THE UNIT ASSEMBLY STAGE SHOWING MINOR BULKHEADS BEING INSTALLED IN THE INVERTED POSITION - OPPORTUNITY UNIT 3130

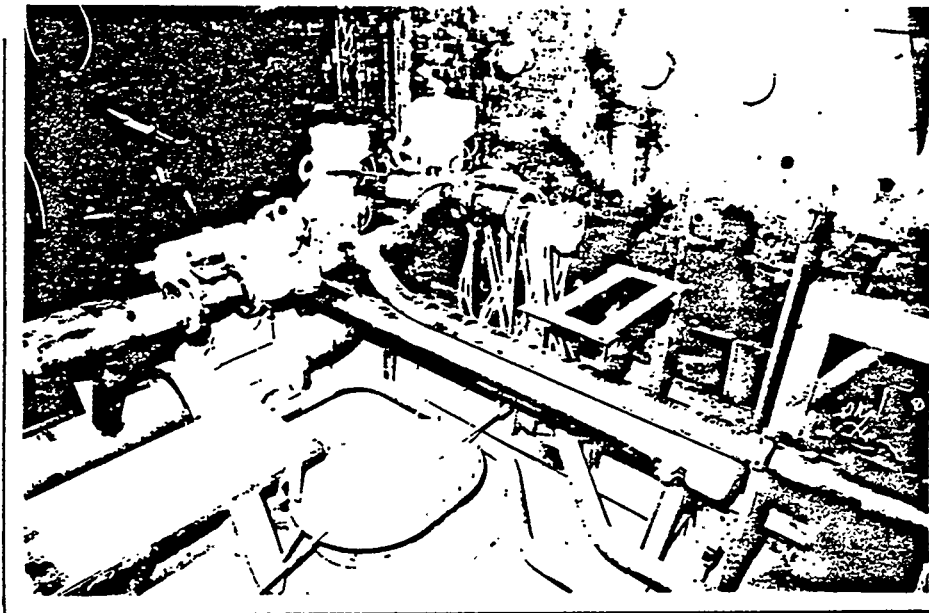
STAGE OF CONSTRUCTION 1420



PRODUCT: UNIT

FIGURE 28. UNIT 1350 SHOWING SEATING ON THE TOP SIDE OF DECK IN ZONE 4110. PRE-OUTFITTING UPRIGHT.

STAGE OF CONSTRUCTION 1420



PRODUCT: UNIT

FIGURE 29. UNIT 2120 SHOWING FOUNDATION, PENETRATION, MANHOLES, ETC. PRE-OUTFITTING UPRIGHT

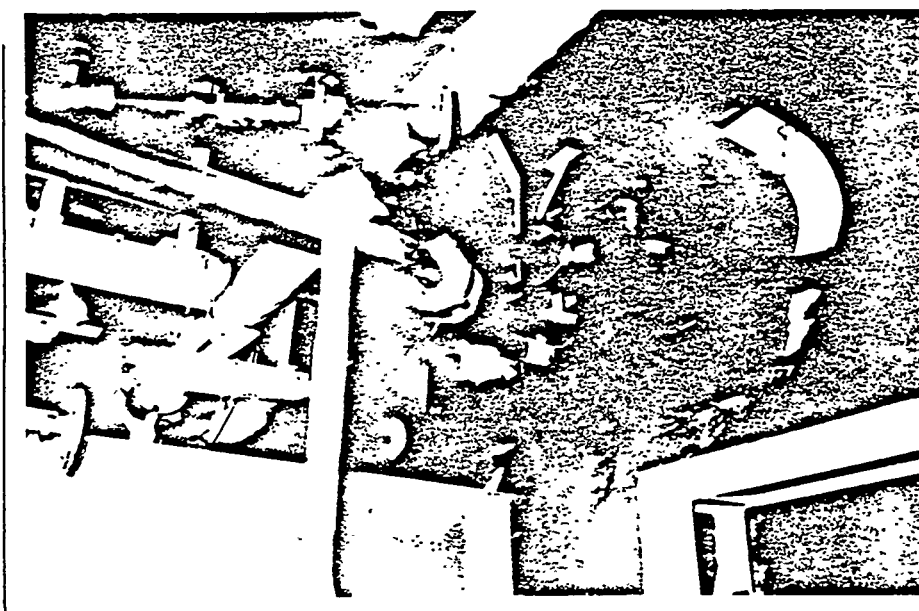
STAGE OF CONSTRUCTION 1700



PRODUCT: UNIT

FIGURE 30. PRE-OUTFIT 2 SHOWING VALVES, VENTILATION, LIGHTING AND INSULATION

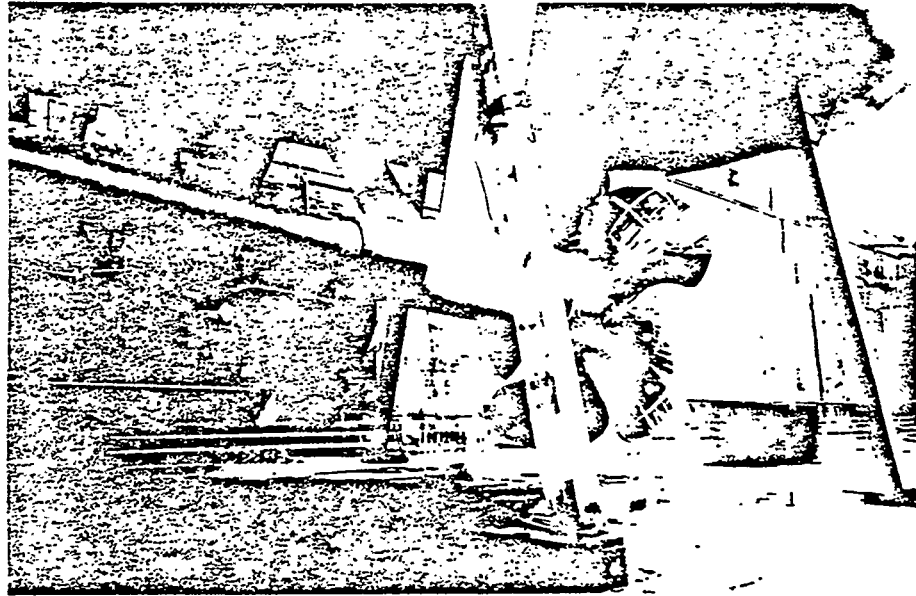
STAGE OF CONSTRUCTION 1700



PRODUCT: UNIT

FIGURE 31. PRE-OUTFIT 2 SHOWING VALVE INSTALLATION AND INSULATION

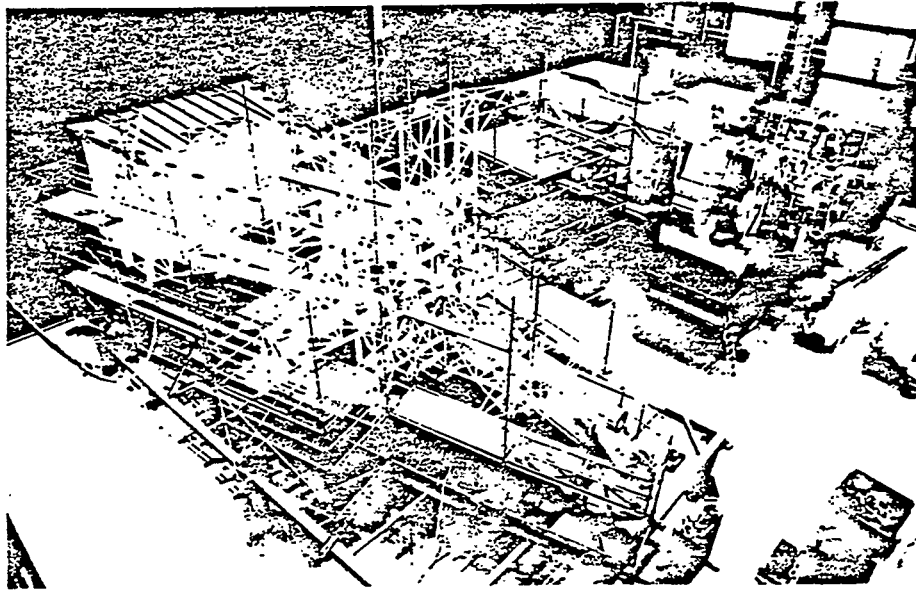
STAGE OF CONSTRUCTION 1800



PRODUCT: SPECIAL INSTALLATIONS

FIGURE 32. INSTALLING SHAFTING AND PROPELLERS

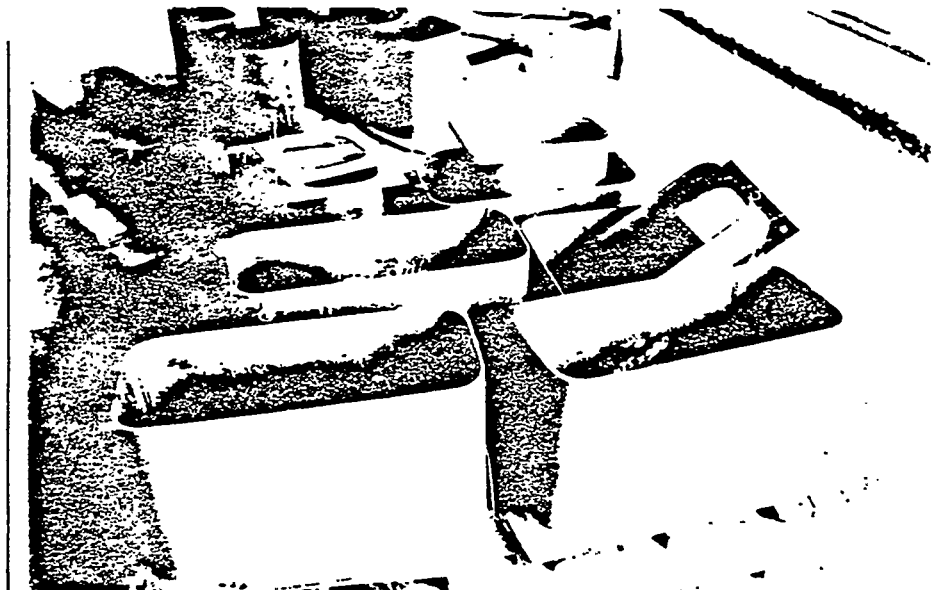
STAGE OF CONSTRUCTION 1500



PRODUCT: MODULES

FIGURE 33. INSTALLING GEARBOX AND GAS TURBINES ON RAFT. COMPLETE WITH L.O. COOLING, L.O. PUMPS AND PIPING

STAGE OF CONSTRUCTION 1160



PRODUCT: STANDARD MANUFACTURING JOB

FIGURE 34. PENETRATIONS

STAGE OF CONSTRUCTION 1170



PRODUCT: STANDARD MANUFACTURING JOB

FIGURE 35. FIRE HOSE RACKS

4. DEVELOPING THE TRANSLATION MATRIX

The original CPF contract ICWBS established the framework for performance measurement and management of the CPF program. At the time of contract negotiation and signing it was decided that the product of the contract WBS would be a ship system, that all cost/performance data would relate to that ship system, and that the ICWBS would be organized accordingly. However, shipyard functional organizations became increasingly frustrated by their inability to report and monitor performance in a manner in keeping with the way they were building the ship - by PRODUCT. Contributing to this frustration was the inability to perform the following functions accurately:

- o Adjust manning levels because of early or late shifts in product production
- o Integrate operational (or recovery) schedules into day-to-day performance objectives
- o Report timely corrective action to cost/schedule variances
- o Forecast the impacts of late material or drawing delivery
- o Identify and evaluate the impact of engineering changes on both hull construction and zone outfitting.

These analytic deficiencies, coupled with the ongoing rationalization of fundamental shipbuilding processes and concomitant redesign of the SJSI organizational structure, called the entire concept of performance reporting by ship system into question. It became increasingly clear that comprehensive performance measurement structured in the same manner in which the PRODUCT (in this case a ship) is built affords considerable analytic possibilities. It can provide that margin needed for outstanding growth and profitability, and, when coupled with sound planning, furnish a substantial framework of objectives and strategies to form the basis for responsible decision-making. There are ancillary benefits as well, including the development of a powerful communications conduit through which managers both disclose and gain visibility into problems limited to specific areas or affecting performance in the entire shipyard.

However, before a total commitment was made to move CPF contract method of reporting to a

Product by Stage of Construction (P/Sc) method, two major questions were raised concerning the Cost/Schedule Control Criteria:

Firstly, how effective will the "new direction" be in achieving the stated C/SC contract objectives (to employ effective management control systems for cost/schedule planning and control of major program elements, and provide useful data on cost, schedule and technical performance); secondly, can the "new direction" report and integrate actual cost at the proper level of the contract ICWBS for historical recording?

Considerable effort was expended to answer these questions by broadening the rationalization process to include the C/SC Criteria. Starting with the ORGANIZATION and moving progressively through the Criteria to REVISIONS, it was determined that P/se reporting is capable of supporting the contract ICWBS. Indeed, a P/Se WBS would achieve literal compliance with all C/Sc Criteria requirements. This further implied that a quantitative method of moving from the ICWBS to P/Se WBS and back to the ICWBS would be developed for reasons of traceability. Additionally, relationships between the stages of transition would have to be clearly expressed and identified. The technique for performing this quantitative movement between ICWBS and PRODUCT is depicted by the Translation Matrix (Figure 36).

4.1 TRANSLATION BETWEEN ICWBS AND PRODUCT

No single, accurate method of determining the amount of budget to be allocated to each PRODUCT from each element of the ICWBS existed. Indeed, even the most experienced estimators would employ different methods, depending upon such factors as the type of ICWBS element, the particular product in question, and the level of accuracy required.

Because of this ambiguity and lack of definition it was necessary to establish a common ground. Firstly, a definition of PRODUCT was agreed:

A PRODUCT is any physical Unit or Outfit Zone (to that level detail required for control and performance measurement), Special Installation (detailed by Engineering and Planning), Module (as designed by Engineering and incorporated into Product drawings), and Manufacturing

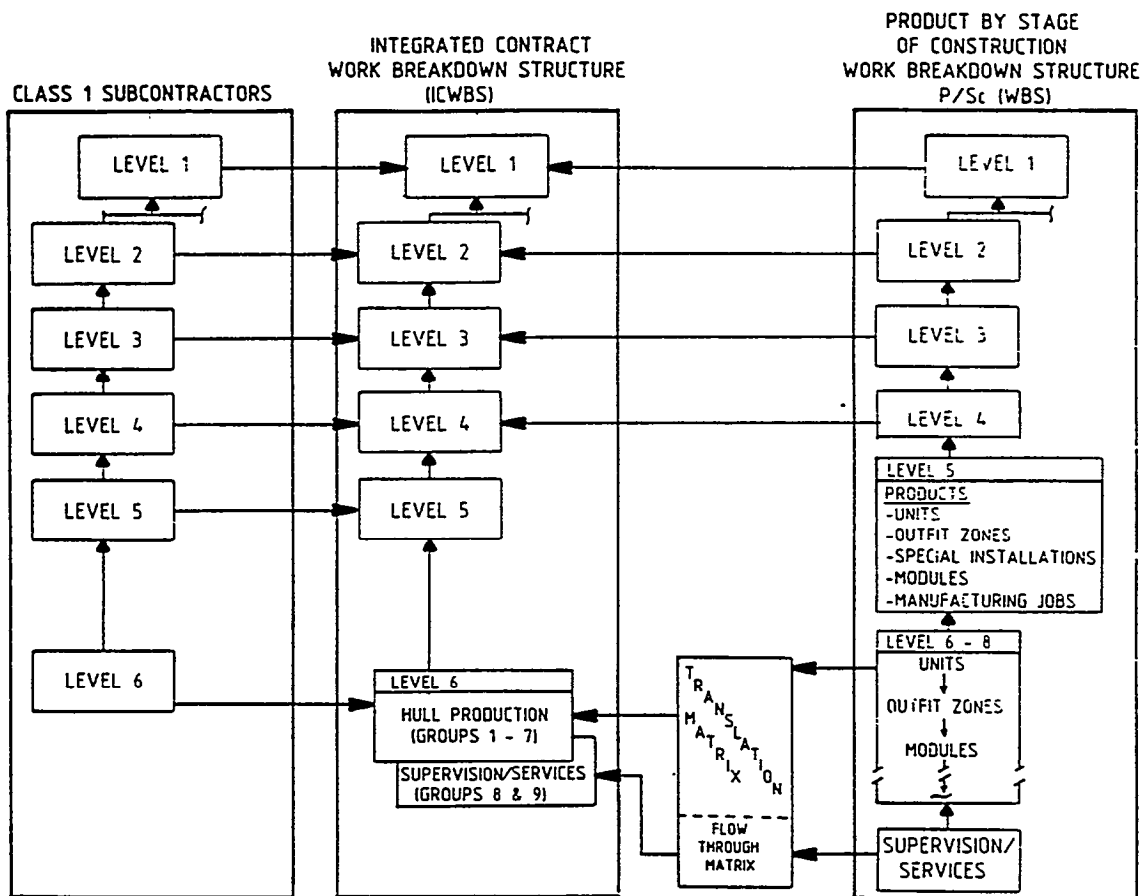


FIGURE 36. THE TRANSLATION MATRIX

Job (as defined by Engineering and Planning). A PRODUCT starts as a part to which another part is added at a Stage of Construction. The PRODUCT is always defined in conjunction with the optimum Stage of Construction.

Secondly, a fundamental theory was postulated and agreed:

There can be an allocation and effective distribution of the ICWBS budget to a PRODUCT at a Stage of Construction most opportune fabricate or install the PRODUCT. This distribution starts at a high level and is sub-divided into assembly, sub-assembly, component and part until each PRODUCT has a portion of budget correctly correlated with its particular Stage of Construction. As the allocation descends the PRODUCT hierarchy, the process of budget distribution becomes progressively more complex; final decisions of correct allocation are subject to a qualitative analysis.

Once this process is completed and the total budget is assigned by PRODUCT, the Performance Baseline Model is effectively sealed against further manipulation or modification; through linkage with the Integrated Master Schedule, it becomes a basis for TRUE PERFORMANCE MEASUREMENT.

Finally, a Translation Simulation Model was developed to compare the strengths and weaknesses of each translation and, more importantly, to track and label the assigned system budget to the PRODUCT.

At this point, the Translation Simulation Model is used only to pre-test proposed distributions of the ship system (ICWBS) budget to a PRODUCT.

The pre-testing performed by the computer and subsequent analysis by the planner trace, in detail, the implications and consequences of selected ICWBS distributions. Substantial effort was expended during the design stage of the model to incorporate the "rules of distribution". Broadly speaking, these rules focus on defining and analyzing correct algorithms for budget distribution.

Once the correct algorithms were defined, the following questions were applied:

- o Do the algorithms accomplish what is desired?
- o How do they perform?
- o How good is the distribution "on the average"?
- o How average is average? That is, what is the variance in distribution?

Analysis and manipulation of the three conceptual elements - PRODUCT, budget allocation by PRODUCT, and the Translation Simulation Model - culminated in the development of a two-axis Translation Matrix. With this matrix, it is possible to identify at any point of intersection the resources required to achieve "an element of the ICWBS by a Product" (Figure 37).

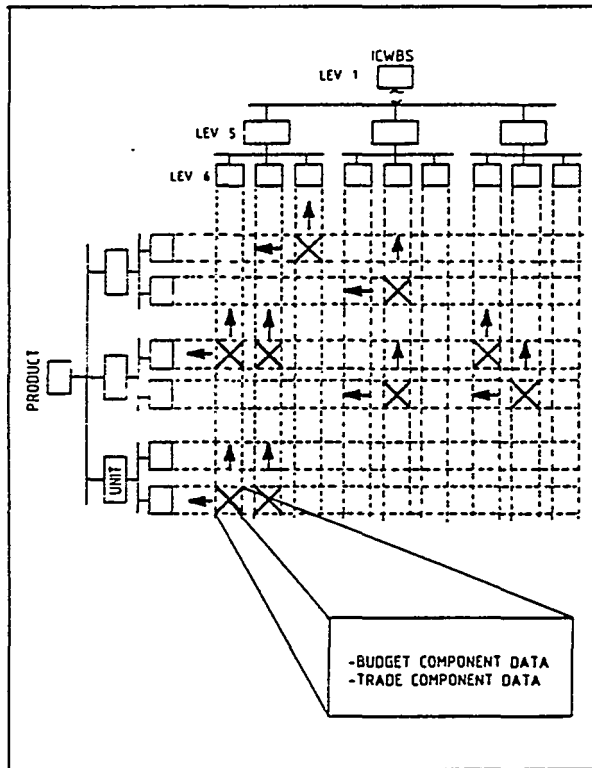


FIGURE 37. THE OUTPUT OF THE TWO-AXIS TRANSLATION MATRIX

The matrix offers a great deal of clarity in the initial translation, allowing the planner to "see" the distribution of resources (budget and trade component data) over the complete shipbuilding process (the PRODUCT). Furthermore, through the Simulation Model, the matrix may be adjusted and fine-tuned to incorporate or simulate changes.

4.2 TRANSLATION BETWEEN PRODUCT AND STAGE OF CONSTRUCTION

The effective distribution of the complete ICWBS budget across the PRODUCT paves the way for the second step of the translation process: distribution of the PRODUCT budget across the Stages of Construction.

The Translation Simulation Model was extended to make distributions and comparisons in three dimensions. This extension was taken to a sufficiently low level of detail to allow its use as a guide for finally establishing the budget for installation of a PRODUCT at the optimum Stage of Construction.

The extension of the Translation Simulation Model was controlled by designing the following characteristics into the model:

4.2.1 FEASIBILITY

Some Product/ICWBS/Stage of Construction combinations are more amenable to distribution than others in that they can be apportioned with a high level of confidence. However, combinations which must accommodate transitions through basic, functional and detail design are only "approximated"; this is because the information for these combinations is less than complete at different stages of design. As part of the extension of the Translation Simulation Model, all distributions would have an "associated accuracy" value with the final budget distribution.

4.2.2 TESTABILITY

Testability refers to the degree of ease with which corrections to the final distribution may be tested, requiring knowledge of what is correct and documentation of the mechanics for conducting that test.

4.2.3 EFFECTIVENESS

All final distributions have an impact on the analysis of Product performance. For example, a projection of percentage completion is not very reliable if analysis shows that the majority of distributions have a low degree of associated accuracy. On the other hand, accurate data would demonstrate an immediate acceptability.

4.2.4 LOCATABILITY

A sophisticated technique was devised for tagging the ICWBS number and associated budget of each proposed distribution in order to allocate actual cost back to the correct ICWBS account accurately. This technique is able to link and unlink relationships repeatable sequence distributions are iterated to their final conclusion.

4.2.5 MOVEMENT FROM SIMULATION MODEL TO TRANSLATION MATRIX

The final output of the Translation Simulation Model into the Translation Matrix consists of:

- o Product by Stage of Construction Budget
- o Relational Matrix Pointer
- o Performance Contribution [P(x)]

P(x) is the contribution made by the Product at a Stage of Construction to overall ship performance. The sum of all contributions equals completion of the Product, or 100% performance, thus

$$T(p) = \sum [P(x) + \dots + P(n)]$$

where T(p) = Total Performance

P(x) = Contribution of a Completed Product

P(n) = Contribution of the Last Completed Product.

This output is illustrated in more detail at Figure 38.

At this juncture it should be noted that the Integrated Master Schedule is relationally linked to the intersection of Product at a Stage of Construction (see Figure 38). This link is a major factor in the success and acceptance of the P/Se system.

Finally, it must be emphasized that the Translation Simulation Model and resultant Translation Matrix are tightly controlled; changes to any distribution or optimum location of Product must be approved by an Executive Steering Committee, thus ensuring a true and consistent baseline for performance measurement.

4.3 REPORTING COST/SCHEDULE CONTROL AND PRODUCT BY STAGE CONSTRUCTION PERFORMANCE THROUGH THE WORK DESCRIPTION/INSPECTION AND TEST PLAN

The Work Description/Inspection and Test Plan (WD/ITP) is the primary document defining the work required for a Product at a specific Stage of Construction. The resources to accomplish the work tasks are formally assigned through the WD/ITP and are relationally linked to the baseline schedule (IMS) and/or operational schedules. The budget for the WD/ITP is allocated through the Translation Matrix, including both system (ICWBS) and budget data. Through a sub-set of the Relational Matrix, distributed trade data for each stage of construction is accessed. Additional sub-sets provide data for material, kitting, etc. (see Figure 39).

The WD/ITP is the set of all required detailed work instructions, procedures, material lists and processes necessary to plan, perform, and finally accept the work tasks for a specific product at a Stage of Construction. Through the WD/ITP, the work performed (BCWP) is objectively measured and the control and monitoring of work performance is supported. Control is established by task (ICWBS system) through the Product and Stage of Construction.

The WD/ITP has been designed to effectively report and monitor any differences resulting from the performance of work at a stage differing from the designated Optimal/Primary Stage. (See Figures 40, 41, 42 and 43 for a more detailed discussion.) This is accomplished through the unique approach of linking portions of work to Primary Stages of Construction, with the option of performing the work at that stage or at a Secondary Stage of Construction if necessary.

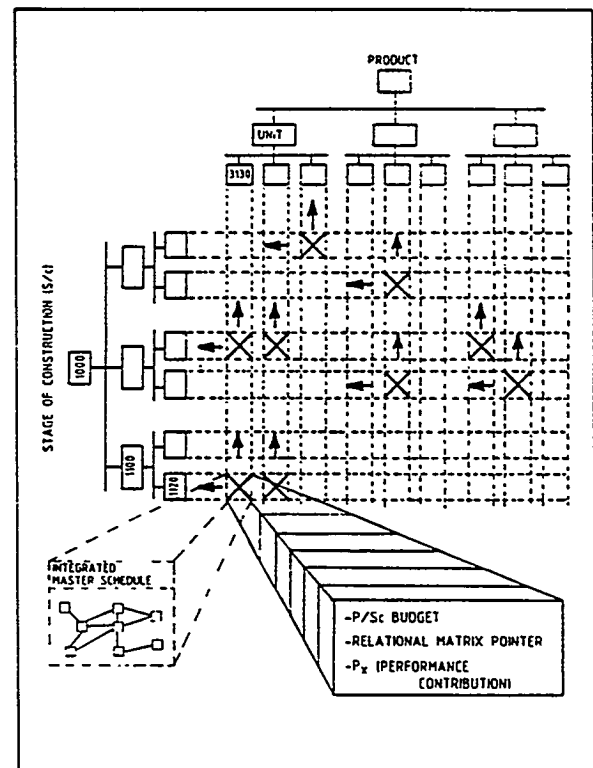


FIGURE 38. THE OUTPUT OF THE THREE-AXIS TRANSLATION MATRIX

The Primary Stage of Construction is the OPTIMUM Stage of Construction for the Product, as determined by planning in relation to available facilities at SJSL. At this Primary Stage, the budget associated with the Product reflects the optimal

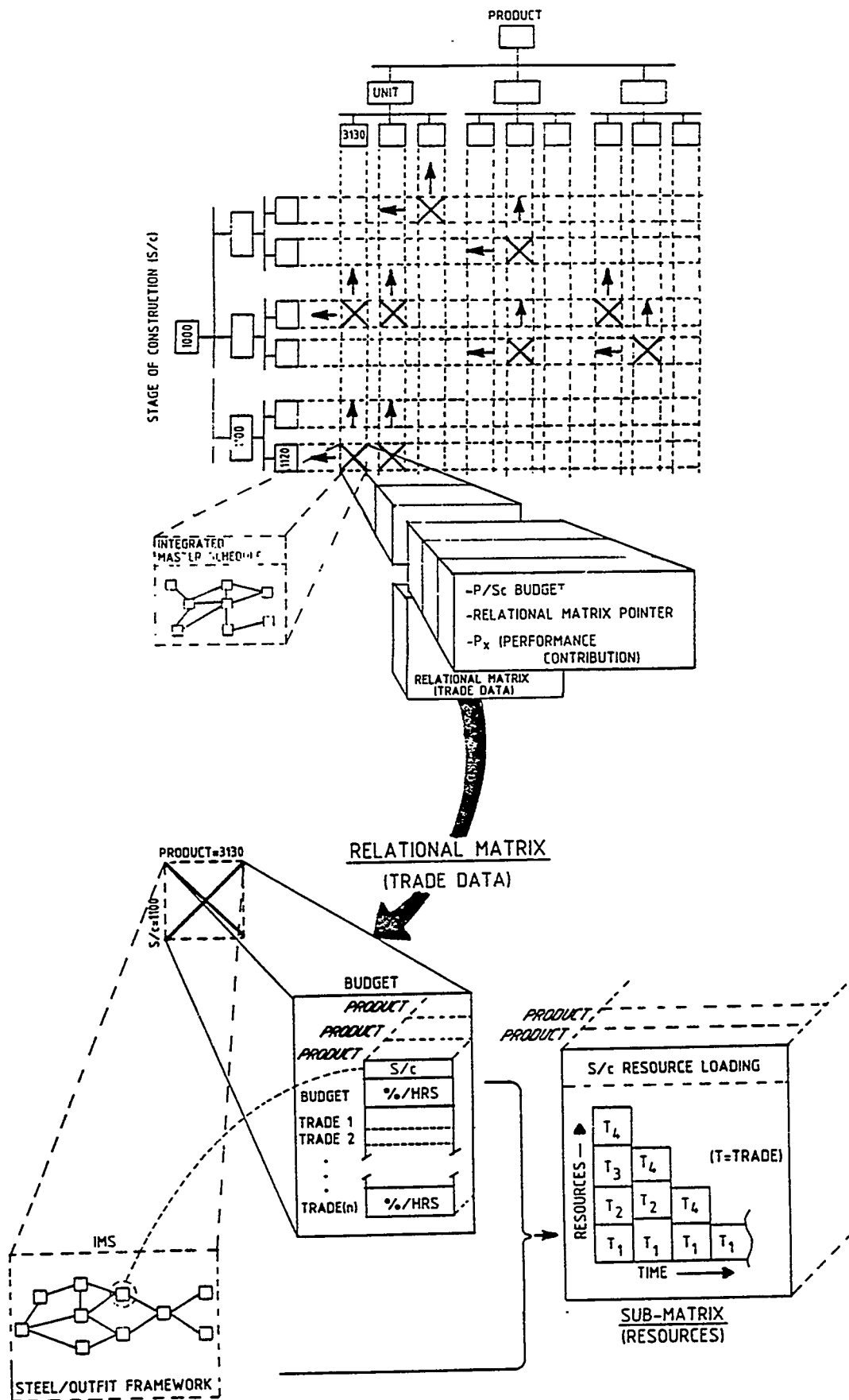


FIGURE 39. AN ILLUSTRATION OF THE RELATIONAL MATRIX POINTER POINTING TO TRADE DATA

FIGURE 40.

PRIMARY DEFINITION OF WORK BY WD/ITP

① --PRIMARY STAGE--			
② WD/ITP NO. 3130.01	SCHEDULE REFERENCES		⑤
③ UNIT NO. 3130	IMS	O/SCH	
④ STAGE NO. 1210	NODE 340.25	NODE 340.25	
	START 03/28/88	START 04/04/88	
	COMPL 04/10/88	COMPL 04/15/88	
TOTAL BCWS 2000			
TASK	SYSTEM	BCWS HOURS	TASK % COMP
⑥ { TASK NUMBER ONE TASK NUMBER TWO TASK NUMBER THREE	1062.2	1300	100%
	1019.0	156	75%
	2621.0	105	10%
	2619.0	252	10%
	2626.0	187	10%
TOTAL AUTHORIZED BCWS		2000	74%
		⑦	⑧
		⑨	⑩
		⑪	

①. PRIMARY STAGE
OF
CONSTRUCTION

- Where all the WORK for a particular product at a particular stage of construction is budgeted and scheduled to be accomplished (OPPORTUNITY).

②. WD/ITP No.

- Unique number for WORK associated with a PRODUCT (unit) at a stage of construction.

③. UNIT NO.

- a four digit number representing a geographical area within the ship used for identifying and scheduling material and labour resources, applicable to a unit or outfit zone (PRODUCTS).

④. STAGE NO.

- a four digit number identifying a physical area where the WORK on a PRODUCT is to be accomplished.

⑤. SCHEDULE
REFERENCE

- includes both Integrated Master Schedule (IMS/ Baseline Schedule) and operating schedule indicating Node Number, Scheduled Start and Scheduled Completion Dates.

IMS

- Integrated Master Schedule (IMS) the baseline Schedule representing the full work scope of a contract.

OPERATIONAL

- Represents the way work is scheduled to be done versus where/when was planned to be done. REALITY.

⑥. TASK

- Description of work tasks which must be accomplished to satisfy the requirements of the WDITP.

⑦. SYSTEM

- ICWBS reference for each work task.

⑧. BCWS

- Budgeted Cost Work Scheduled (BCWS) for the task, by system, as developed through the TRANSLATIONAL MATRIX.

⑨. TOTAL
AUTHORIZED BCWS

- Sum of all budgets for all work tasks of the Primary Stage WD/ITP.

⑩. TASK % COMPLETE

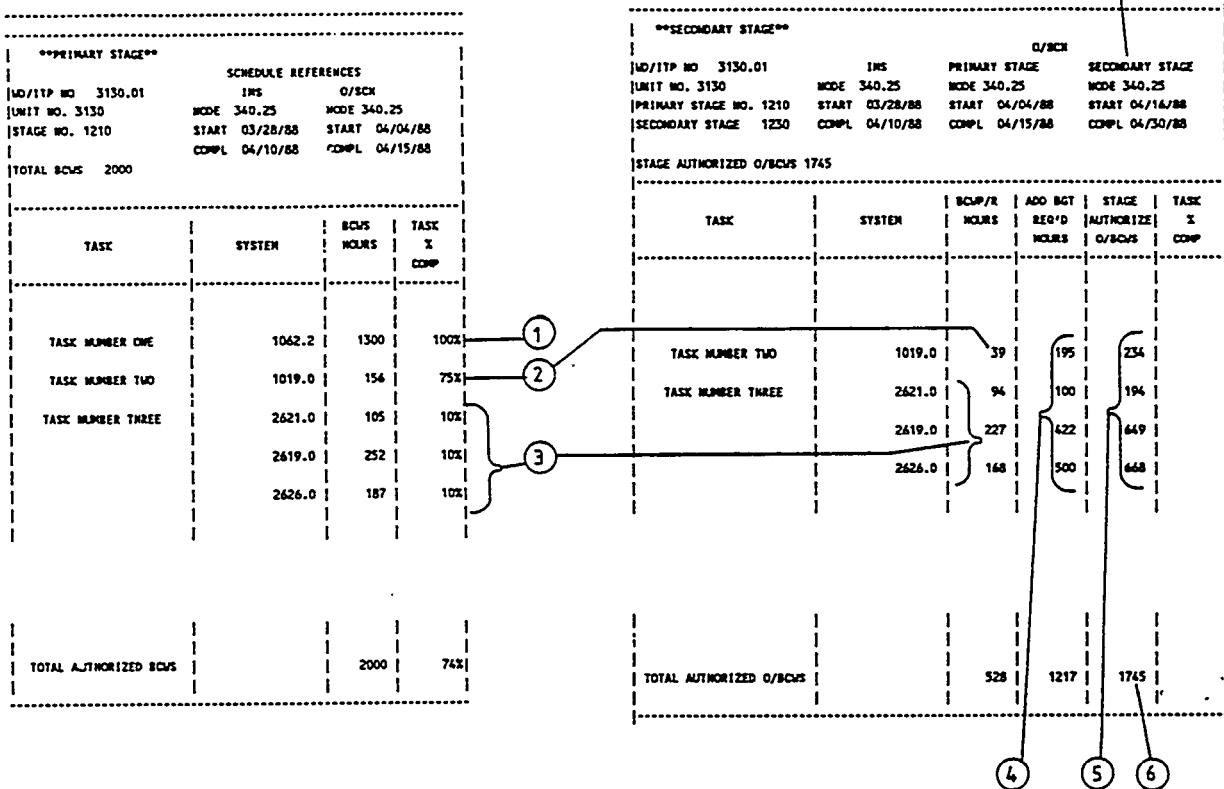
- Cost Account Managers weekly/monthly assessment of % complete for each task (ICWBS relationship).

⑪. WD/ITP % COMPLETE

- Overall % complete for the PRODUCT by STAGE OF CONSTRUCTION.

FIGURE 41

REASSIGNMENT OF WORK BY WD/ITP



The following describes the process followed to reassign scope (BCWP/R) from a primary stage WD/ITP to a secondary stage.

The final status (% complete) of the primary stage is evaluated with the following reassignments of work:

- ① Task 1 is 100% complete therefore no reassignment of work is required.
- ② Task 2 is 75% complete; 25% or 39 hours of scope (BCWP/R) is reassigned to the secondary stage.
- ③ Task 3, which consists of:

TASK	PRIMARY STAGE	PRIMARY STAGE	SECONDARY STAGE
SYSTEM	% COMP	BCWS	HOURS COMP. BCWP/R
2621.0	10%	105	11 94
2619.0	10%	252	25 227
2626.0	10%	187	19 168

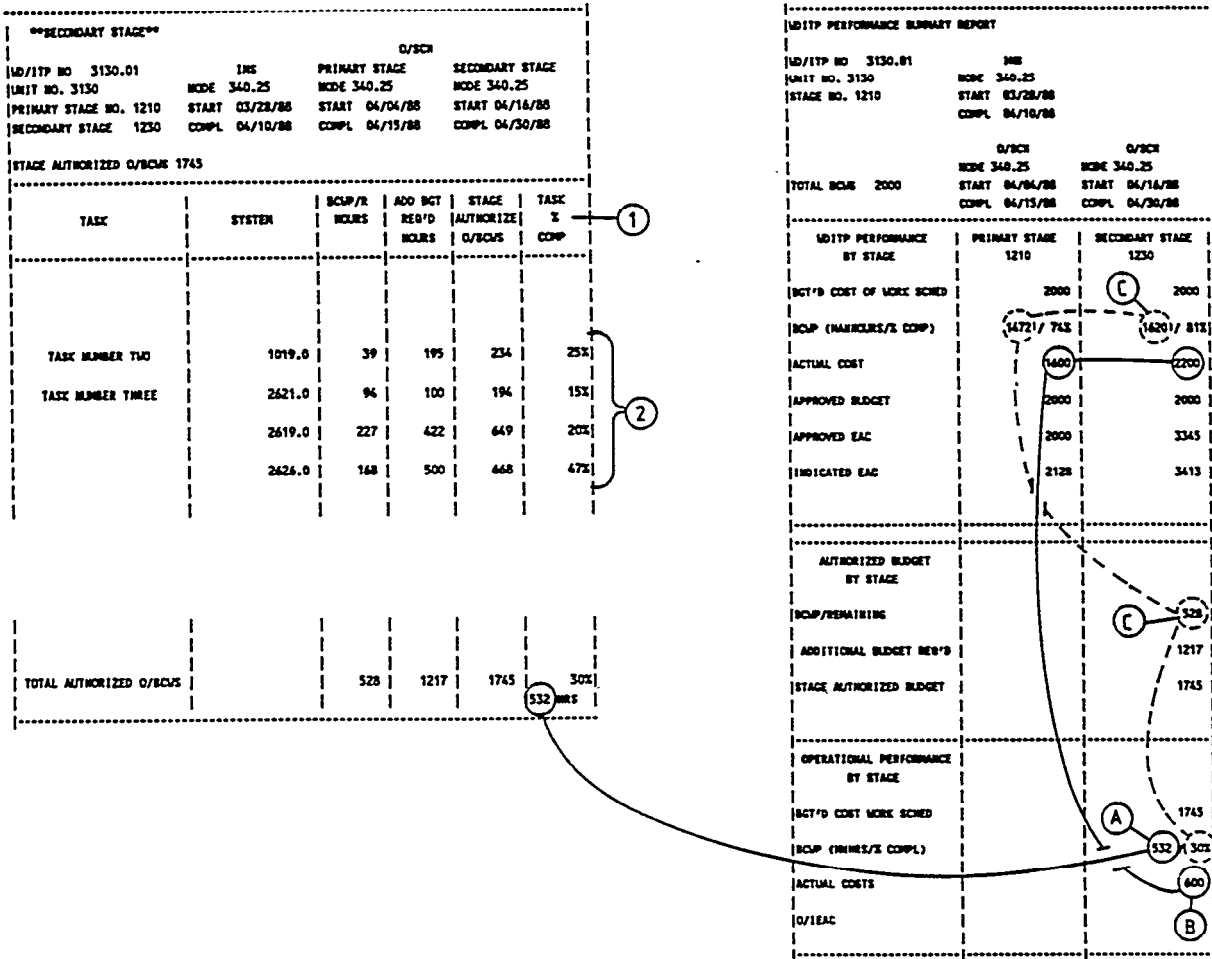
The BCWP/R is reassigned to the secondary stage, and represents the difference between the Primary Stage BCWS and the hours completed (BCWP) in the Primary Stage.

- ④ By task an estimate of the additional budget required (ABR) is performed by the work center manager for the secondary stage. This provides an accurate operating budget against which his performance may be measured.
- ⑤ The "Stage authorized O/BCWS" is the addition of the BCWP/R + ABR. (This is the budget authorized for the secondary stage portion of the WD/ITP.)
- ⑥ The sum of the authorized O/BCWS for the tasks remaining to be completed within the Secondary Stage WD/ITP.
- ⑦ An operating schedule is issued to the secondary stage, which represents that stage's schedule constraints (REALITY).

Note: Responsibility for the work always resides with the Primary Stage WD/ITP.

FIGURE 42

STATUSING OF WORK BY WD/ITP



- Weekly/Monthly performance data, in terms of % complete, is determined by the Cost Account Manager for each task and recorded within the WD/ITP.
- Once this work is statused as a percent complete for the secondary stage the same percent complete is used to automatically update the primary WD/ITP as follows:

WD/ITP				WD/ITP			
SECONDARY				PRIMARY			
TASK	% COMP.	O/BCWS	HRS	TASK	% COMP.	BCWP/M	HRS
PERFORMANCE	.15	194	29	PERFORMANCE	.15	94	14
	.20	649	130		.20	227	45
	.47	668	314		.47	168	79
TOTAL	.30	1745	532	TOTAL	.30	528	148

- This performance data is now assimilated into the WD/ITP Performance Summary Reports as described below.
 - Secondary Stage performance for the WD/ITP is updated to reflect the current % Complete for the stage authorized work (532 manhours/30%).
 - Actual costs for the Secondary Stage are recorded (600 manhours). These actual costs relate to the performance earned to date (532 manhours).
 - WD/ITP Performance is revised to reflect the secondary stage performance to date. To the previous stage BCWP manhours (1472) the Secondary Stage BCWP/R manhours (30% of 528 = 158 manhours) is added, reflecting the overall WD/ITP performance of 1620 manhours (1620/2000 = 81% of complete).
 - ACWP is revised to record all actual costs incurred to date for the primary + secondary stages WD/ITP (1600 + 600 = 2200).
 - EAC for the WD/ITP is equal to the final ACWP (HRS) of the Primary Stage (1600) plus the Stage Authorized O/BCWS for each secondary stage (1745).
 - Indicated EAC represents an appreciation of the EAC based upon the Cost Variance (ie Approved EAC - (BCWP-ACWP)).

FIGURE 43

COMPLETION OF WORK BY WD/ITP

SECONDARY STAGE					
O/SCH					
WD/ITP NO 3130.01	IMS	PRIMARY STAGE	SECONDARY STAGE		
UNIT NO. 3130	NODE 340.25	NODE 340.25	NODE 340.25		
PRIMARY STAGE NO. 1210	START 03/28/88	START 04/04/88	START 05/05/88		
SECONDARY STAGE 1250	COMPL 04/10/88	COMPL 04/15/88	COMPL 05/25/88		
STAGE AUTHORIZED O/BCWS 360					
TASK	SYSTEM	BCWP/R HOURS	ADD BGT HOURS	STAGE O/BCWS	TASK % COMP
TASK NUMBER TWO	1019.0	2	10	12	100%
TASK NUMBER THREE	2619.0	52	176	228	100%
	2626.0	20	100	120	100%
TOTAL AUTHORIZED O/BCWS		74	286	360	100%

WD/ITP PERFORMANCE SUMMARY REPORT				
WD/ITP NO 3130.01	IMS			
UNIT NO. 3130	NODE 340.25			
STAGE NO. 1210	START 03/28/88			
	COMPL 04/10/88			
TOTAL HOURS 2000				
	O/SCH	O/SCH	O/SCH	O/SCH
	NODE 340.25	NODE 340.25	NODE 340.25	NODE 340.25
	START 04/04/88	START 04/16/88	START 05/05/88	START 05/05/88
	COMPL 04/15/88	COMPL 04/30/88	COMPL 05/25/88	COMPL 05/25/88
WD/ITP PERFORMANCE BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250	
BGT'D COST OF WORK SCHED	2000	2000	2000	
BCWP (MANHOURS/X COMP)	1472 / 74%	1926 / 96%	2000 / 100%	
ACTUAL COST	1600	3300	3663	
APPROVED BUDGET	2000	2000	2000	
APPROVED EAC	2000	3345	3660	
INDICATED EAC	2128	3300	3663	
AUTHORIZED BUDGET BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250	
BCWP/REMAINING		528	74	
ADDITIONAL BUDGET REQ'D		1217	286	
STAGE AUTHORIZED O/BCWS		1745	360	
OPERATIONAL PERFORMANCE BY STAGE	PRIMARY STAGE 1210	SECONDARY STAGE 1230	SECONDARY STAGE 1250	
BGT'D COST WORK SCHED		1745	360	
BCWP (MANHOURS/X COMPL)		1501 / 86%	360 / 100%	
ACTUAL COSTS		1700	343	
O/EAC		1700	343	

The work has progressed from the Primary Stage (1210) through Secondary Stage (1230) and finally to Secondary Stage (1250) where the work was completed, as shown above.

- ① Completion of the WD/ITP only occurs when all the work tasks are statused as 100% complete.
- ② The WD/ITP Performance Summary Report records the WD/ITP performance by WD/ITP, and by each Stage of Construction.

With completion of the Work tasks the WD/ITP performance is recorded whereby

- ④ Overall BCWS for the WD/ITP does not change, regardless of the number of secondary stages through which the work is accomplished, hence BCWS remains as 2000 hours.
- ⑤ BCWP equals BCWS, and records 100% complete.
- ⑥ Actual costs are updated to record all costs incurred on the WD/ITP (including costs incurred through the primary and all secondary stages).

- ⑦ Approved Budget remains as originally issued, and cannot be revised unless a formal revision is authorized.

- ⑧ Approved EAC represents that estimate approved for the overall WD/ITP. This value is revised as the work is reassigned to secondary stages. A final adjustment is required to set the approved EAC equal to the ACWP (and hence the indicated EAC).

- ⑨ Indicated EAC, for the completed WD/ITP, equals total ACWP.

- ⑩ The flowthrough of status information from the stage WD/ITP's (secondary) occurs as follows:

- ① The Secondary WD/ITP registers 100% complete with the finalization of all work tasks.
- ② The 100% complete of the Secondary WD/ITP automatically picks up the BCWP/Remaining for the overall WD/ITP, as a manhour value, and assesses this portion of work as complete. (74 manhours).
- ③ The overall WD/ITP manhour performance is revised to incorporate the completion of the BCWP/R work tasks (74 manhours). Hence BCWP is equal to 1926 + 74 manhours = 2000 or equal to the total WD/ITP Budget.

allocation of resources. Should the product be completed at any other stage, a negative cost impact could be realized; Secondary Stages of Construction accommodate performance of work but may incur cost and schedule deviations.

The work described on the WD/ITP is cracked from the Primary Stage through to its completion, regardless of the number of secondary Stages of Construction through which it might be performed. With the movement of the Product to the next construction stage, the WD/ITP tasks are statused and the remaining work is reassigned through the WD/ITP to Secondary Stages for completion. Consequently, the WD/ITP, at any point in time, represents the performance of work completed (BCWP) and the exact assessment of the performance required to complete the work remaining (EAC). This represents a major step in performance measurement systems, as it allows the shipyard to take stock of day-to-day objectives, in real time, and preclude the impact of subjective statusing of in-process work.

Formally, the process is accomplished through the systematic closing out of each completed task defined in the ND/ITP as the work moves from one stage to another. When the schedule dictates that the Product moves to another stage, but some of the work tasks have not yet been performed or are incomplete, a status is prepared and recorded. The WD/ITP for the current stage is closed, and records performance for that stage only. The work tasks which remain outstanding are then reassigned to the next stage through the same WD/ITP, with the budget remaining from the Primary Stage WD/ITP also transferred. budget (BCWS) authorized for the WD/ITP does not change from that which was authorized at the Primary Stage.

The remaining work is evaluated by the Secondary Stage Superintendent who will reassess work requirements and recommend increases (operational budgets) through an Estimate to Complete (ETC). Ultimately the total estimate authorized to production through the Secondary Stage(s) WD/ITP represents a reasonable estimate and schedule to perform the remaining work.

If need be, this process is repeated through further Secondary Stages until the work is completed. Each Stage of Construction Superintendent is responsible to perform the work on behalf of the Primary Stage

Superintendent (Primary Stage WD/ITP), but is also accountable for performance of the work within his stage.

SJSL has linked the C/SC Baseline with the Operational Baseline through the WD/ITP. The reporting mechanism supports the preservation of detailed historical data by Product, Stage and ICWBS and further supports stability of the baseline, as all reassignments of task are formally recorded.

Overall performance against the WD/ITP is recorded at each stage and variance analysis is performed where applicable.

Conclusion

The integration of Product by Stage of Construction with a Cost/Schedule Control application results in a solid framework of cost and schedule data that forms a basis for sound planning and decision making.

The Translation Simulation model described in this paper is designed not only to effect the *transition* from the ship system (ICWBS) to the Product approach, but also affords traceability for historical and control purposes and provides a sealed model against which to measure and report progress.

As illustrated in Figure 44, P/Se and ICWBS data are synthesized through the model and correctly assembled in the WD/ITP. The application of Integrated Master Schedule requirements and actual cost of accomplished work (ACWP) to the WD/ITP represents a comprehensive technique for measuring exact performance (BCWP) at a given point in time.

At time of publication, Saint John Shipbuilding Limited is engaged in dialogue with the Contracting Authority to integrate Product by Stage of Construction reporting formally into existing C/SC performance documents, and looks forward to validation of the P/Se system as implementation progresses and matures.

Concurrent combined use of P/Se and C/SC systems breaks new ground in Canadian and perhaps North American shipbuilding industry. It is hoped this paper will stimulate and provide a basis for further investigation into this comprehensive approach to project management, reporting and control.

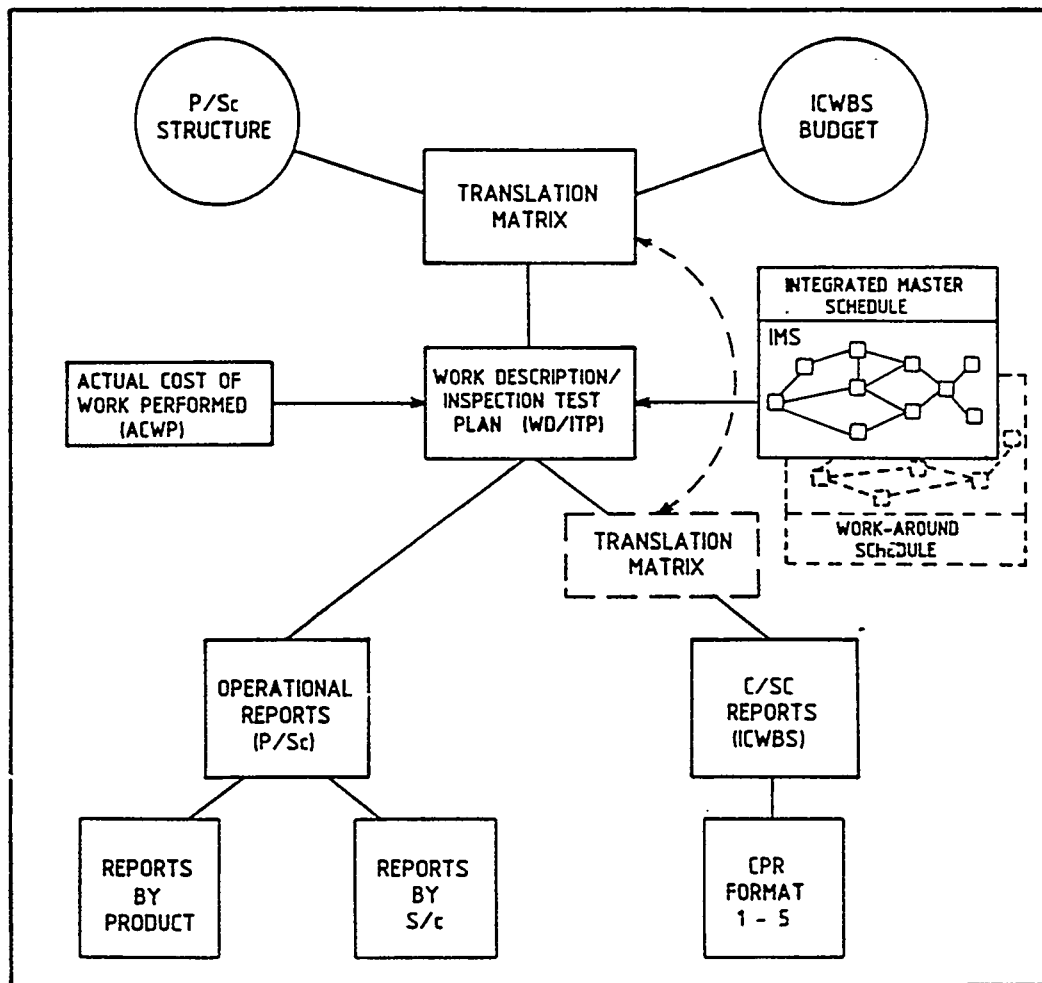


FIGURE 44 . THE SUCCESSFUL INTEGRATION OF PRODUCT BY STAGE OF CONSTRUCTION WITH COST/SCHEDULE CONTROL APPLICATION
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REFERENCES

1. L.D. Chirillo et al., Pipe Piece Family Manufacturing, NSRP, Maritime Administration, March 1982.
2. T. Lamb, "Engineering for Ship Production," Journal of Ship Production, Vol. 3, No. 4, November 1987.

- Structure," U.S. Department of Transportation, Maritime Administration, 1982.
4. Y. Okayama and L.D. Chirillo. Product Work Breakdown Structure, NSRP, Maritime Administration. Revised December 1982.
5. R.L. Storch et al., Ship Production, Cornell Press, Centreville, Maryland, 1988.
6. F.A. Graybill, An Introduction to Linear Statistical Models, Vol. 1, McGraw-Hill, New York, 1961.
7. J. Riordan, An Introduction to Combinatorial Analysis, John Wiley and Sons, New York, 1958.

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